UNIVERSITÉ DU QUÉBEC À MONTRÉAL

ÉTUDE ISOTOPIQUE SUR LE CYCLE DU CARBONE DISSOUS ET LA PRODUCTION DE GAZ À EFFET DE SERRE LORS DE LA CRÉATION D'UN RÉSERVOIR HYDROÉLECTRIQUE BORÉAL (Eastmain-1, Nouveau Québec)

MÉMOIRE

PRÉSENTÉ

COMME EXIGENCE PARTIELLE

DE LA MAÎTRISE EN SCIENCES DE LA TERRE

PAR

ANNIE LALONDE

MARS 2009

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AVANT-PROPOS

Le présent mémoire est présenté sous la forme d'un article scientifique qui sera soumis à la revue *Science of the Total Environment* (Elsevier), sous le titre: *Isotopic insight on dissolved carbon cycling and greenhouse gas production at the inception of a boreal hydroelectric reservoir (Eastmain-1, New Quebec)*. Par conséquent, les références se trouvent à la fin de l'article. Deux autres auteurs ont participé à la rédaction de l'article ; mon co-directeur de maîtrise, le Dr Jean-François Hélie et mon directeur de maîtrise, le Dr Claude Hillaire-Marcel.

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Afin de faciliter la lecture des tableaux, les noms des colonnes ont été contractés comme suit :

- Alk : alkalinité
- Aq : aqueux
- Atm : atmosphérique
- C : carbone
- Cond. : conductivité
- Temp. : température
- Prod. : produit
- [DIC] : concentration de CID
- [DOC] : concentration de COD
- [POC] : concentration de COP

RÉSUMÉ

Le réservoir Eastmain-1 (est de la Baie de James, Nouveau Québec) a été inondé de novembre 2005 à mai 2006. Il s'étend sur une superficie de 603 km^2 et possède une profondeur d'eau moyenne de 11,5 m, ce qui lui confère des conditions holomictiques lors des périodes libres de glace. Cette recherche a pour objectif l'étude du cycle du carbone organique et inorganique dissous (COD & CID) suite à la création du réservoir. Pour ce faire, l'analyse élémentaire C/N de la matière organique dissoute et particulaire, ainsi que l'analyse isotopique de tous les composés du carbone – incluant le CO_2 atmosphérique à la surface du réservoir- ont été réalisées, suite à cinq campagnes de terrain menées de Juin 2006 à Juillet 2007. Une relation linéaire négative est observable entre les valeurs δ^{13}C-CID et l'inverse de la pression partielle de CO_2 ($1/pCO_2$), avec une ordonnée à l'origine de -23,7 ± 01,0‰. Cette valeur correspond à la composition isotopique d'un CID en quasi-équilibre avec le CO_2 produit *in situ* par l'oxydation de la matière organique dissoute (MOD) du réservoir. Les valeurs élevées des ratios C/N de cette MOD indiquent une origine majoritairement terrestre. Le second pôle de cette relation linéaire correspond à des conditions d'équilibre avec le CO_2 atmosphérique ambiant, portant la signature de la forêt boréale avoisinante. Selon les conditions de températures, d'hydraulicité, d'agitation des vents, etc., les pCO_2 et les compositions isotopiques mesurées se dispersent autour de la courbe de mélange, ce qui suggère un système de plus faible inertie en comparaison avec les réservoirs plus âgés et de plus vastes étendues de la région de la Baie de James. Toutefois, la légère tendance temporelle en ^{13}C du CID, de 2006 à 2007, pourrait suggérer une évolution vers des conditions plus stables suite aux hauts taux d'oxydation du COD lors de la mise en eau du réservoir.

MOTS CLÉS : réservoirs hydroélectriques, CO_2, carbone organique dissous, ^{13}C, C/N, Baie de James, Québec

INTRODUCTION GÉNÉRALE

Bien que l'hydroélectricité soit considérée par plusieurs comme une des formes de production d'énergie les plus propres par rapport aux autres méthodes de production, tous les réservoirs hydroélectriques produisent des gaz à effet de serre (GES), soit CO_2, CH_4 et, en moindre proportion, N_2O (e.g. Duchemin *et al.*, 2002; Hélie, 2004; Kelly *et al.*, 1997; St.Louis *et al.*, 2000; Tremblay *et al.*, 2004). Il a été démontré que les émissions de GES des réservoirs situés en région boréale se font majoritairement sous forme de CO_2. En effet, les émissions de CH_4 y sont marginales et les émissions de N_2O sont généralement négligeables. En comparaison, les températures plus élevées des réservoirs des régions tropicales favorisent les émissions de CO_2 et surtout de CH_4 (e.g. Duchemin *et al.*, 1995; Gagnon et Chamberland, 1993; Huttunen *et al.*, 2002). Des études récentes ont démontré l'importance d'estimer les émissions nettes de GES par les réservoirs hydroélectriques (Tremblay *et al.*, 2005). Les écosystèmes naturels – tels les lacs, rivières, forêts et tourbières – peuvent agir comme puits ou sources de GES selon les conditions hydriques et thermiques dans lesquelles ils se trouvent. L'immersion de vastes territoires inhibe la fixation du carbone ainsi que la photosynthèse de la végétation terrestre tout en stimulant potentiellement sa décomposition, favorisant la production microbienne de CO_2 et, dans une plus faible mesure, de CH_4 (Aberg *et al.*, 2004; Tremblay *et al.*, 2004). De plus, en raison des débits d'eau plus importants dans les réservoirs que dans les lacs naturels, la quantité de carbone allochtone y est significativement plus grande (Bambace *et al.*, 2007) et est alors susceptible d'y être décomposée. Cependant, quelques milieux particuliers, telles les tourbières, sont généralement considérés comme des puits de CO_2, mais comme des sources de CH_4 et N_2O.

Dans cette optique, Hydro-Québec Production, en collaboration avec la Fondation Canadienne pour les Sciences du Climat et de l'Atmosphère (FCSCA), a mis sur pied un projet multidisciplinaire afin de déterminer les émissions nettes de GES par un réservoir hydroélectrique boréal (Réservoir Eastmain-1, nord-est du Canada – http://www.eastmain1.org). Ce projet d'envergure regroupe des compagnies privées, des agences gouvernementales ainsi que différentes universités et comporte cinq volets principaux : volet "aquatique", volet "terrestre", volet corrélation "Eddy" – soit l'utilisation d'une station météorologique automatique dans le but de mesurer les flux de CO_2 émis à la

surface du réservoir –, volet "modélisation" et le volet "isotopique", sujet de la présente recherche.

Des études antérieures, basées sur des analyses isotopiques (^{13}C) couplées à des analyses élémentaires (C/N) de la matière organique dissoute (MOD), ont démontré que le carbone inorganique dissous (CID) du profond réservoir hydroélectrique Robert-Bourassa (profondeur moyenne de 22 m), situé à environ 250 km au nord du réservoir Eastmain-1, et mis en eau de novembre 1978 à l'automne 1979, provient majoritairement de l'oxydation de la MOD (Hélie, 2004 ; Luther, 2000). Dans un réservoir âgé d'environ 25 à 30 ans, l'oxydation de la biomasse inondée semble être marginale (Hélie, 2004). L'approche isotopique s'est ainsi révélée un bon outil pour déterminer les sources du CO_2 émis à la surface du réservoir et a permis de mieux comprendre le cycle du carbone qui lui est associé. Nous avons donc utilisé cette approche afin d'étudier la problématique du carbone associé à la création d'un nouveau réservoir de faible profondeur (profondeur moyenne de 11,5 m). Différentes études ont en effet démontré que les émissions de GES à partir des réservoirs boréaux sont plus importantes au cours des premières années suivant leur mise en eau, puis diminuent par la suite (Duchemin *et al.*, 1995; St. Louis *et al.*, 2000; Tremblay *et al.*, 2005).

ISOTOPIC INSIGHT ON DISSOLVED CARBON CYCLING AND GREENHOUSE GAS PRODUCTION AT THE INCEPTION OF A BOREAL HYDROELECTRIC RESERVOIR (Eastmain-1, New Quebec)

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Abstract

The Eastmain-1 reservoir (eastern James Bay, New Quebec) was flooded from November 2005 until May 2006. It covers 603 km^2 and has an average water depth of 11.5 m, resulting in holomictic conditions when ice-free. This study aims at documenting the cycling of dissolved organic and inorganic carbon (DOC & DIC) following the reservoir impoundment. It is based on elemental C/N analysis of particulate and dissolved organic matter, and isotopic analysis of all carbon compounds including the atmospheric CO_2 over the reservoir, sampled during five intervals from June 2006 until July 2007. A linear negative relationship links overall δ^{13}C-DIC values to the reverse of pCO_2, with a Y-intercept value of -20.8 ± 0.8‰. This intercept corresponds to a DIC near isotopic equilibrium with the CO_2 produced *in situ* by dissolved organic matter (DOM) oxidation. High C/N ratios in DOM indicate it is mostly of terrestrial origin. The other end-member of the linear relationship corresponds to equilibrium conditions with the ambient atmospheric CO_2, carrying a boreal forest signature. Depending on temperature conditions, hydraulicity, wind speed, etc., measured pCO_2 and isotopic compositions are scattered around the corresponding decreasing exponential mixing curve, suggesting therefore a lower inertia system, in comparison with larger and older reservoirs from the James Bay area. However, a slight temporal trend in δ^{13}C-DIC values, from 2006 to 2007, may suggest a trend toward steadier conditions following the high DOC-oxidation rates of the flooding period.

KEYWORDS: hydroelectric reservoirs, CO_2, dissolved organic carbon, ^{13}C, C/N, James Bay, Quebec

1. Introduction

Although hydropower is considered by many as one of the "greenest" form of energy production compared to other energetic methods, all hydroelectric reservoirs produce greenhouse gas emissions (GHG): CO_2, CH_4 and, to a lesser extent, N_2O (*e.g.* Duchemin *et al.*, 2002; Hélie, 2004; Kelly *et al.*, 1997; St.Louis *et al.*, 2000; Tremblay *et al.*, 2004). For boreal reservoirs, it has been demonstrated that their GHG emissions are mainly in the form of CO_2. In these environments, emissions of CH_4 are generally marginal and N_2O emissions are usually negligible (Hélie, 2004; Houel *et al.*, 2006; Tremblay *et al.*, 2005). In comparison, higher temperatures of tropical reservoirs promote CO_2 and especially CH_4 emissions (*e.g.* Duchemin *et al.*, 1995; Gagnon and Chamberland, 1993; Huttunen *et al.*, 2002). Recent studies have underlined the importance of estimating net GHG emissions from hydroelectric reservoirs (Tremblay *et al.*, 2005). Natural ecosystems, such as lakes, rivers, forests and peatlands, can either act as a GHG source or a sink depending on their hydric and thermic conditions. Flooding large land areas inhibits carbon fixation and photosynthesis of terrestrial vegetation and stimulates its decomposition, enhancing microbial production of CO_2 and, to a lesser extent, CH_4 (Aberg *et al.*, 2004; Tremblay *et al.*, 2004). Furthermore, due to larger flow rates than in natural lakes, the amount of allochthonous carbon is significantly larger in hydroelectric reservoirs (Bambace *et al.*, 2007) and could become available to decomposition. However, some environments, such as peatlands, are globally considered to be CO_2 sinks but CH_4 and N_2O sources.

A multi disciplinary project has been launched to determine net GHG emissions of a newly-flooded boreal hydroelectric reservoir (Eastmain-1, north-eastern Canada-http://www.eatmain1.org). Various studies have shown that GHG emissions from boreal reservoirs are more important during the early years following their flooding and then decline thereafter. Also, previous studies, using carbon stable isotopes signatures (^{13}C) coupled with elemental analysis (C/N) of dissolved organic matter (DOM), have demonstrated that dissolved inorganic carbon (DIC) of the deep boreal hydroelectric reservoir Robert-Bourassa (mean depth of 22 m), located about 250 km north of the Eastmain-1 reservoir and flooded from November 1978 to autumn of 1979, originates mainly from the oxidation of DOM in the reservoir (Hélie, 2004; Luther, 2000). In this 25 to 30 years old reservoir, the oxidation of

flooded biomass seems to be marginal (Hélie, 2004). The carbon stable isotopes approach has proven to be an efficient tool for determining the sources of CO_2 emitted at the reservoir's surface therefore providing crucial information on its carbon cycling.

In this study, stable carbon isotopes and elemental analysis are used to constrain carbon sources and cycling at the inception of a shallow boreal hydroelectric reservoir (mean depth of 11.5 m).

2. Material and methods

2.1 Study area

The Eastmain-1 hydroelectric reservoir (52°10'N, 75°50'W) is located in the James Bay area, eastern Canada (Figure 1). It covers an area of 603 km^2 with an average shallow depth of 11.5 m and is fed by the Eastmain River. Flooding of the reservoir began in November 2005 and ended in May 2006. Before flooding, the area was covered with approximately 65% boreal forests, 21% rivers and lakes and 14% peatlands. The climate is characterized by a mean annual temperature of -2.4°C (average monthly maximum and minimum temperatures of 22.4°C and -29.0°C respectively) and mean annual precipitations of 731.9 mm for 2003 to 2005 (Environment Canada). In this region of the Superior Province, the Precambrian bedrock is mainly igneous. The study area is located within the volcano-sedimentary Eastmain River Belt, which lies in the greenstone belt and metasedimentary rocks of the Canadian Shield (Brosseau, 2008). None of the lithology found in the watershed contains carbonate minerals. The land morphology and unconsolidated sediment cover are inherited from the activity of the Laurentide Ice Sheet during the last Wisconsinan ice advance and its subsequent retreat. Characteristic glacial and post-glacial morpho-stratigraphic units are present: from basal till, ground moraine, ablation till, glaciofluvial and glaciolacustrine deposits; to deltaic, prelittoral and littoral, aeolian, alluvional and organic deposits (Brosseau, 2008). These units are characterized by very low amount of carbonates, as no unit contains more than 2.5% of $CaCO_3$ over the entire flooded land.

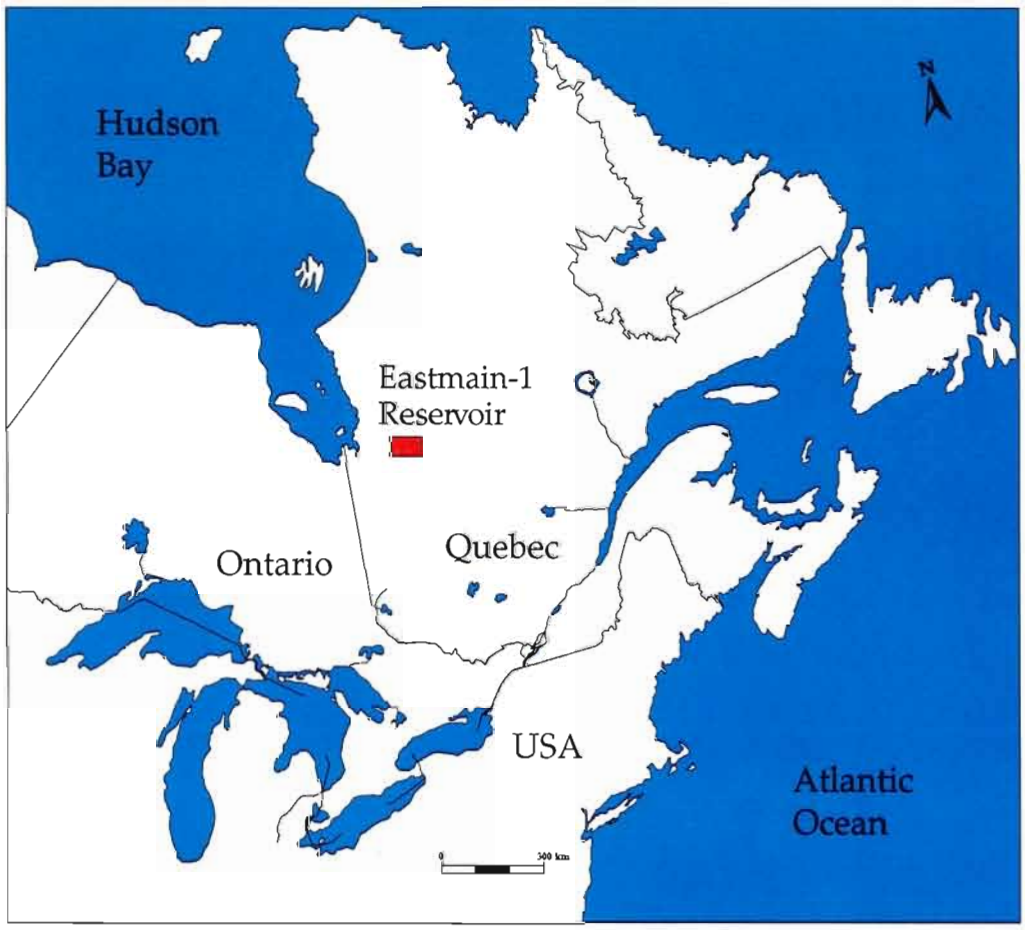

Figure 1. Location map of the Eastmain-1 hydroelectric reservoir (New Quebec).

2.2 Field sampling and laboratory analyses

Five sampling campaigns were carried out during the ice-free period: in June 2006, August 2006, October 2006, June 2007 and July 2007. The surface water (0-5 cm deep) and its overlying air were sampled in twelve sites in the reservoir and in one natural lake nearby (Figure 2 and Table 1). Water columns were also sampled in three of these sites, at depths of 2, 4, 6 and 8 m during the first campaign and at depths of 5, 10 and 15 m for the other four campaigns. Moreover, in June and August 2006, one site was sampled during the night (*Tour-1*, Figure 2). At every site, *in situ* measurements were made and several water sub-samples were collected and processed for subsequent laboratory analysis.

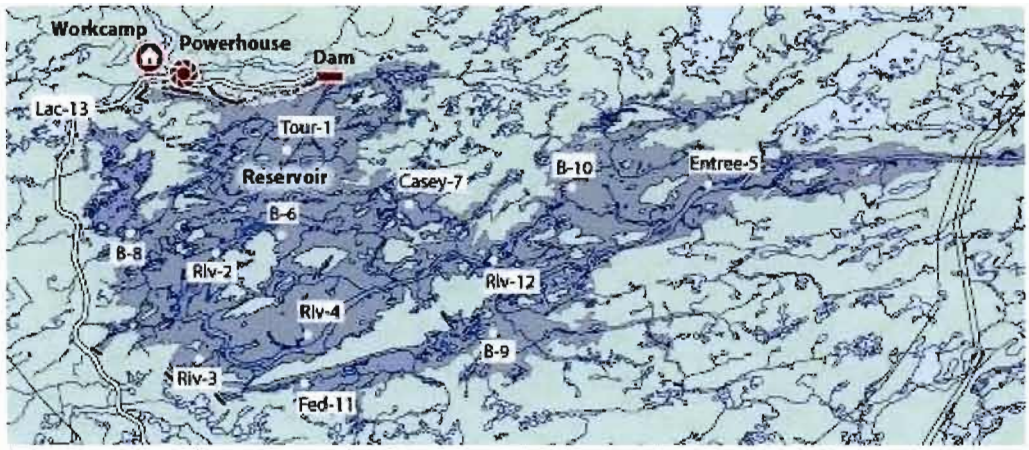

Figure 2. Sampling sites on the Eastmain-1 hydroelectric reservoir, (New Quebec).

Table 1. Sampling sites location. *Lac-13* is the only site (in a natural lake) outside the reservoir.

Sampling sites	Latitude	Longitude
Tour-1	52° 07.979'	75° 55.603'
Riv-2	52° 04.470'	76° 00.400'
Riv-3	52° 00.405'	76° 01.038'
Riv-4	52° 01.570'	75° 54.370'
Entrée-5	52° 07.342'	75° 29.319'
B-6	52° 05.236'	75° 56.247'
Casey-7	52° 06.404'	75° 47.780'
B-8	52° 05.360'	75° 05.090'
B-9	52° 01.050'	75° 42.044'
B-10	52° 07.200'	75° 37.380'
Fed-11	51° 59.717'	75° 54.085'
Riv-12	52° 04.418'	75° 42.513'
Lac-13	52° 09.025'	76° 10.276'

At each sampling site and sampling campaign, water temperature and pH were measured *in situ* using a Thermo Orion model 250A™ pH meter, with a 1σ-reproducibility of ±0.1 °C and ±0.03 pH units, respectively. Air temperature (σ = ±1°C) and wind speed (σ = ±0.1m s^{-1}) were measured using a Kestrel 2000™ anemometer. Conductivity was measured using a YSI Model 30™ conductimeter (σ = ±0.5 µS cm^{-1}). Alkalinity was determined using a Hach Digital Titrator™ and a Thermo Orion model 250A™ pH meter following the Gran Function Plot method with a precision of σ ±0.005 meq l^{-1}. For the water column depth profiles, a YSI™ 6600 model multi-probe was used, equipped with temperature, conductivity, dissolved oxygen, pH and pressure [i.e., water depth] sensors (σ = ±0.15 °C, ±0.5 µS cm^{-1}, ±0.2 mg l^{-1}, ±2%, ±0.02 pH units and ±0.3 m, respectively). The total water depth was also measured using a Hondex™ Digital Depth Sounder (σ = ±1%).

All analyses were performed at the stable isotopes laboratory of the GEOTOP Research Center. Air samples for the analysis of $\delta^{13}C$ of air CO_2 at the water-air interface were collected in Labco Exetainer® vials previously vacuumed (residual pressure of about 50 millitorr) and capped with Kel-F/septa caps after sampling. Duplicates were collected. Air samples were analysed with a Micromass Isoprime™ IRMS mass spectrometer coupled to a MicroGas™ in continuous flow mode (with an overall sample variability of ± 1‰ estimated from replicate measurements). The same equipment was used for the analysis of $\delta^{13}C$ of dissolved inorganic carbon in water samples (overall analytical uncertainty of ± 0.2‰). Water samples were collected in brown glass bottles capped with Polyseal™ caps poisoned with solid mercury chloride ($HgCl_2$) to inhibit bacterial and algal activity and then stored at 4°C until analysis. No air was left in the bottles to avoid isotopic exchange with ambient air CO_2. Particulate organic matter (POM) in water samples was recovered by filtering water through a pre-combusted and pre-weighted 0.3 µm pore-size glass microfibre filter (Whatman EPM2000™). The filter was then acidified with 0.1M sulphuric acid to eliminate potential carbonates and kept frozen until analysis. Part of the filter was used to analyze particulate organic carbon (POC) concentration, particulate organic nitrogen (PON) concentration and C/N mass ratios using a Carlo Erba NC 2500™ Elemental Analyzer (σ = ± 0.1% for carbon concentrations and ±0.2% for nitrogen concentrations). Another part was used to analyze $\delta^{13}C$-POC using an Elemental analyzer Carlo Erba NA1500™ coupled with a Micromass

Isoprime™ IRMS mass spectrometer in continuous flow mode ($\sigma = \pm 0.1‰$). Part of the filtered water was collected in a brown glass bottle for the analysis of dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC) concentrations, using a O-I Analytical Model 1010™ TIC-TOC analyzer ($\sigma = \pm 0.04$ mg l^{-1}). Part of the filtrate was also collected in a 250 ml polypropylene centrifuge bottle, acidified with HCl to eliminate DIC and kept frozen until the analysis of DOM. The samples were freeze-dried using a Labconco™ Freeze dry system upon return to the laboratory. Part of the freeze-dried material was analyzed for $\delta^{13}C$ of DOM ($\sigma = \pm 0.2‰$) with the same instrument as for the analysis of the $\delta^{13}C$-POC. They were performed in triplicates and weighed in tin cups. The balance of the freeze-dried material was analyzed using a Carlo Erba NC 2500™ Elemental Analyzer for the determination of the DOM C/N ratio ($\sigma = \pm 0.1\%$ for carbon concentrations and 0.2% for nitrogen concentrations). Isotopic results are given using the standard δ notation with: $\delta = [(R_{sample}/R_{reference})-1] \times 1000$, where $R = {}^{13}C/{}^{12}C$. All δ-values are reported in per mil (‰) against V-PDB (Coplen, 1995).

2.3 Calculations

POC concentrations are calculated using %C given by the elemental analysis on the filter multiplied by the weight of sediment recovered on the filter and divided by the amount of filtered water on the field.

The different DIC species concentrations are calculated using a classical carbonate chemical system where CO_2 reacts with water to form carbonic acid, then some of the carbonic acid dissociates to form bicarbonate and hydrogen ions and finally some of the bicarbonate will dissociate to an additional hydrogen ion and a carbonate ion as:

$$[1]\ CO_2 + H_2O \leftrightarrow H_2CO_3^* \leftrightarrow H^+ + HCO_3^- \leftrightarrow 2H^+ + CO_3^{2-}$$

These reactions are associated to three equilibrium equations related to their dissociation constants as follows:

$$[2]\ K_{CO_2} = \frac{[H_2CO_3^*]}{[pCO_2]}$$

$$[3]\ K_1 = \frac{[H^+][HCO_3^-]}{[H_2CO_3^*]}$$

$$[4]\ K_2 = \frac{[H^+][CO_3^{2-}]}{[HCO_3^-]}$$

Where species concentrations are given in moles per litre and pCO_2 is in µatm. The equilibrium equations are thermo-dependant and given as the following three equilibrium equations (Clark and Fritz, 1997):

$$[5]\ pK_{CO_2} = -7 \cdot 10^{-5} \cdot T^2 + 0.016 \cdot T + 1.11$$

$$[6]\ pK_1 = 1.1 \cdot 10^{-4} \cdot T^2 - 0.012 \cdot T + 6.58$$

$$[7]\ pK_2 = 9 \cdot 10^{-5} \cdot T^2 - 0.0137 \cdot T + 10.62$$

The total DIC concentration in water is given by the sum of carbonic acid, bicarbonate and carbonate concentrations:

$$[8]\ [DIC] = [H_2CO_3^*] + [HCO_3^-] + [CO_3^{2-}]$$

$\delta^{13}C$-DIC combined with concentrations of the different carbonate species (dissolved CO_2, HCO_3^- and CO_3^{2-}) give the isotopic composition of these three different carbonate species ($\delta^{13}C_{CO2diss}$, $\delta^{13}C_{HCO3}$-, $\delta^{13}C_{CO3}{}^{2-}$) using the following equations system:

$$[9]\ \left(\delta^{13}C_{CO_{2diss.}} \cdot \frac{[CO_{2.diss}]}{[DIC]}\right) + \left(\delta^{13}C_{HCO_3^-} \cdot \frac{[HCO_3^-]}{[DIC]}\right) + \left(\delta^{13}C_{CO_3^{2-}} \cdot \frac{[CO_3^{2-}]}{[DIC]}\right) = \delta^{13}C_{DIC}$$

$$[10]\ \frac{\delta^{13}C_{CO_2diss.} + 10^3}{\delta^{13}C_{HCO_3^-} + 10^3} = \alpha_1$$

$$[11]\ \frac{\delta^{13}C_{CO_3^{2-}} + 10^3}{\delta^{13}C_{HCO_3^-} + 10^3} = \alpha_2$$

$$[12]\ 10^3 \operatorname{Ln} \alpha_1 = 9.866\left(\frac{10^3}{T}\right) - 24.12 \quad \text{(Mook } et\ al.\text{, 1974)}$$

$$[13]\ 10^3 \operatorname{Ln} \alpha_2 = -0.867\left(\frac{10^3}{T}\right) + 2.52 \quad \text{(Mook } et\ al.\text{, 1974)}$$

All the results from *in situ* measurements, laboratory analysis and additional calculations for each field campaign are presented in Appendice A. Table 2 presents the average values of all sampling sites for each campaign.

3. Results

3.1 At the surface of the reservoir

3.1.2 Physico-chemical parameters

During the study period, water temperature varied between 7.4 and 19.4°C, and was generally a few degrees below the air temperature, which varied between 2 to 20°C. Average pH was 6.08 ± 0.16, mildly increasing from an average of 5.98 ±0.11 in June 2006 to an average of 6.19 ±0.12 in June 2007, with a slight decrease in July 2007. The mean specific conductivity did not exhibit much variation, with an average of 14.0 µS cm^{-1} (excluding data from June 2006, when the specific conductivity was 0.1 µS cm^{-1}) and uniform over the entire reservoir. These acidic pH and low conductivity values reflect very low ionic strength. The dissolved oxygen content (vs. oxygen saturation) ranged from 43.1% to 122.3% with a mean of 93.1%. It has been higher in 2007 campaigns than in 2006 ones. Alkalinity was low, averaging 0.046 meq l^{-1} and ranging from 0.018 to 0.131 meq l^{-1}. Finally, pCO_2 (calculated using DIC concentrations) ranged from 963 to 3686 µatm, being higher in August 2006, with a mean pCO_2 of 2425 µatm and then decreasing gradually.

Table 2. Average analytical results and standard deviations for the entire Eastmain-1 hydroelectric reservoir.

Campaign	Air temp. (°C)	Wind speed ($m\ s^{-1}$)	Water temp. (°C)	pH	Conductivity ($\mu S\ cm^{-1}$)	Alkalinity ($meq\ l^{-1}$)	[POC] ($mg\ l^{-1}$)	[DIC] ($mg\ l^{-1}$)	[DOC] ($mg\ l^{-1}$)
June 2006	17 ± 4	4.2 ± 1.4	14.9 ± 1.3	5.98 ± 0.11	0.1 ± 0.1	0.025 ±5	0.03 ± 0.01	1.21 ± 0.17	7.39 ± 0.48
August 2006	16 ± 2	5.1 ± 1.7	17.8 ± 0.8	6.03 ± 0.11	12.0 ± 0.7	0.047 ± 12	0.04 ± 0.01	1.76 ± 0.34	6.58 ± 0.77
October 2006	7 ± 3	5.3 ± 1.0	10.4 ± 0.4	6.14 ± 0.08	17.0 ± 0.6	0.077 ± 35	0.02 ± 0.01	1.77 ± 0.29	7.07 ± 0.45
June 2007	8 ± 3	3.2 ± 1.6	10.5 ± 1.7	6.19 ± 0.12	n.a	0.045 ± 14	0.06 ± 0.01	1.44 ± 0.24	5.81 ± 0.23
July 2007	16 ± 2	2.6 ± 1.1	15.0 ± 1.4	6.03 ± 0.31	n.a	0.036 ± 11	n.a	1.03 ± 0.26	6.37 ± 0.35

Campaign	δ^{13}C-POC (‰)	δ^{13}C-DIC (‰)	δ^{13}C-DOC (‰)	C/N POM	C/N DOM	pCO_2 (µatm)	$\delta^{13}CO_2$ atm (‰)	$\delta^{13}CO_2$ aq (‰)	Dissolved oxygen content (%)
June 2006	-28.6 ± 1.0	-18.7 ± 1.1	-27.4 ± 0.1	10.29 ± 2.00	50.72 ± 8.44	1569 ± 476	-13.1 ± 1.9	-21.3 ± 1.0	81.2 ± 18.7
August 2006	-29.9 ± 0.7	-18.3 ± 1.5	-27.4 ± 0.2	9.65 ± 0.46	44.67 ± 5.25	2364 ± 638	-15.2 ± 0.7	-21.6 ± 0.8	79.5 ± 11.5
October 2006	-28.9 ± 1.0	-16.9 ± 1.0	-27.4 ± 0.2	8.40 ± 0.61	35.36 ± 3.35	1782 ± 360	-14.6 ± 0.6	-20.6 ± 1.0	97.1 ± 6.0
June 2007	-30.3 ± 1.5	-14.7 ± 1.0	-27.7 ± 0.2	10.82 ± 1.28	39.71 ± 4.82	1447 ± 256	-11.4 ± 0.7	-18.5 ± 1.2	114.1 ± 18.6
July 2007	n.a	-15.0 ± 2.0	n.a	n.a	n.a	1309 ± 607	n.a	-18.5 ± 1.6	93.4 ± 2.5

3.1.3 Carbon concentrations and elemental compositions

POC concentrations were low, ranging from 0.01 to 0.08 mg l^{-1}. DIC and DOC concentrations were definitely higher than POC ones. DIC concentrations reached the highest values in October 2006 with an average of 1.8 mg l^{-1} and then decreased during subsequent campaigns, down to an average of 1.0 mg l^{-1} for the last one. DOC concentrations ranged from an average of 5.8 to 7.4 mg l^{-1}. C/N ranged from 7.1 to 13.0 for POM, and from 30.2 to 57.5 for DOM, decreasing significantly during the first three campaigns, from June 2006 to October 2006.

3.1.4 Isotopic measurements

The δ^{13}C-POC varied from -33.3‰ to -27.2‰, exhibiting no particular trend from one campaign to the next. δ^{13}C-DIC increased gradually, starting with an average of -18.7‰ at the first campaign and reaching an average of -14.9‰ for the last two campaigns. The isotopic signatures of DOC did not show any variation, between the campaigns with a global δ^{13}C-DOC average of -27.5 ± 0.2‰. Finally, the $\delta^{13}C$-CO_2 of the atmosphere reached its lowest values in August 2006, with an average of -15.2‰, and then increased up to an average of -11.4‰ during the last campaign.

3.2 Water column profiles

All the water column profiles are shown in Appendice B. No significant differences were observed between night and day sampling at the *Tour-1* site.

3.2.2 Physico-chemical parameters

The overall shallow nature of the reservoir combined with the windy condition prevailing in the area contributed to the mixing of the entire water column during most of the study period for all physico-chemical parameters. Consequently, water temperature, pH, alkalinity, conductivity and dissolved oxygen profiles remained relatively uniform during each campaign.

During the first campaign, the *Tour-1* sampling site exhibited a distinct thermocline with a temperature gradient of 3°C at a depth of about 7 m (6 m-deep during the day and 8 m-deep during the night). At all other sampling periods, the water column was well mixed without any evidence of stratification. Finally, pCO_2 generally increased with depth at all sampling sites and during each visit.

3.2.3 Carbon concentrations and elemental compositions

In June 2006, the fluctuations of DIC concentrations confirm the presence of a thermocline at about 7 m depth. For all other campaigns, concentrations of POC, DIC and DOC do not show any particular trends with depth. The same observation applies for C/N ratios in POM and DOM, although DOM-C/N exhibited wide fluctuations from surface to lake-bottom, but without any clear pattern.

3.2.4 Isotopic measurements

While showing variations with depth, δ^{13}C-DIC does not exhibit any clear trend, except for the day and night profiles at the *Tour-1* site, in June 2006, where a clear division at the thermocline depth was observed. The same observation applies for δ^{13}C-POC. However no particular trend was observed during other campaigns whatever the sampling site. δ^{13}C-DOC did not show any significant changes with depth, remaining nearly constant between –28 and –27‰ , at all sampling sites of all campaigns.

4. Discussion

4.1 Sources and cycling of organic matter

DIC in freshwater systems can be generated from two major processes: oxidation of organic matter and dissolution of carbonate minerals. In view of the low amounts of carbonates found in the watershed geology and the pH measured in the reservoir, the second process can be ruled out. Oxidation of organic matter may occur in three different places: i) in soils of the watershed, ii) in the reservoir itself, including oxidation of flooded organic matter, and iii) in the Eastmain River upstream of the reservoir (see similar discussions in Hélie, 2004; Pawellek and Veizer, 1994; Telmer and Veizer, 1999). Isotopic signatures ($\delta^{13}C$) of POC and DOC coupled to their respective C/N ratio can help to weight the relative importance of OM sources and their subsequent cycling in aquatic ecosystems (*e.g.* Countway *et al.*, 2007; Lamb *et al.*, 2006; Meyers, 1994). Unfortunately, in this study, $\delta^{13}C$-values are rarely conclusive. Indeed, terrestrial vegetation from boreal forest prominently follows the Calvin-Benson cycle photosynthetic pathway (C3 plants) and thus shows an average $\delta^{13}C$-value of ~ -28‰ (ranging from -23 to -34‰ - Deines, 1980), relatively similar to isotopic composition of freshwater phytoplankton, which utilizes dissolved CO_2 for photosynthesis, thus yielding $\delta^{13}C$-values in the -25 to -33‰ range (Meyers, 1994; Middelburg and Nieuwenhuize, 1998). However, C/N ratios of freshwater phytoplankton and algae differ from those seen in terrestrial vegetation. Terrestrial material is predominantly composed of cellulose and lignin, which have low nitrogen content compared with carbon, and consequently depict high C/N (Lamb *et al.*, 2006). Inversely, aquatic phytoplankton and algae, which have high nitrogen content compared with carbon, have low C/N ratios ranging from 4 to 10 (Meyers, 1994).

In the Eastmain-1 reservoir, low C/N and $\delta^{13}C$ values of POM, averaging respectively 9.67 ± 1.42 and -29.33 ± 1.22‰, suggest the predominance of lacustrine algae contribution with a minor contribution of vascular plant material. Conversely, the high C/N of DOM in the reservoir, ranging from 35.36 ± 3.35 to 50.72 ± 8.44 and its average $\delta^{13}C$ values of -27.5 ± 0.5‰ are those expected for organic matter deriving from C3 terrestrial plants that are

dominant in the area. Thus, the degradation of the reservoir POM does not significantly contribute to DOM. Indeed, as illustrated by previous studies, DOM of boreal reservoirs is mainly terrestrial in origin (Hélie, 2004; Luther, 2000).

C/N-ratios measured in Eastmain-1 DOM decreased significantly during the first three campaigns, from 50.72 ± 8.44 in June 2006 to 35.36 ± 3.35 in October 2006. This trend can be linked to two processes: i) an increasing in situ (aquatic) OM production and contribution to DOM (Meyers, 1994) or ii) the enhanced evolution of organic matter from terrestrial origin in the reservoir linked to increasing OM residence time (e.g., Lobbes *et al.*, 2000). The first explanation is not likely for the month of October 2006. Photosynthesis was probably reduced, because of the low temperature and solar radiation during this time of the year. The second process seems thus more plausible. The slight increase observed in June 2007 (C/N of DOM averaged 39.71 ± 4.82), probably illustrates inputs of "fresh" terrestrial organic matter in the reservoir during the spring snowmelt.

4.2 Isotopic constrains on DOC-DIC budgets

As mentioned above, previous studies have already demonstrated that DIC stems from the oxidation of DOM in the reservoir itself (Hélie, 2004; Luther, 2000), based on the inverse relationship observed between DIC isotopic signatures and concentrations. Figure 3 shows the δ^{13}C-DIC versus pCO_2 relationships observed in the Eastmain-1 reservoir for the study period (ice-free condition). The biggest symbols represent the average values for each campaign. This relationship seems to be governed by mixing of an atmospheric equilibrated end-member CO_2 with an *in situ* CO_2 production end-member. High pCO_2 in the reservoir are linked to ^{13}C depleted DIC δ-values. The atmospheric end-member, corresponding to equilibrium conditions with the ambient atmospheric CO_2, has a δ^{13}C-DIC value around -4‰ based on the worldwide average given by NOAA in 2001 (Anonym, 2001) and a pCO_2 around 384 ± 20 µatm (based on the average pH and temperature of the reservoir during the sampling period). The asymptote defined for high pCO_2 conditions, linked to high rates of

DOM oxidation, has a δ^{13}C-DIC average value of -20.8 ±0.8‰ (Y-intercept of regression fit of Figure 3).

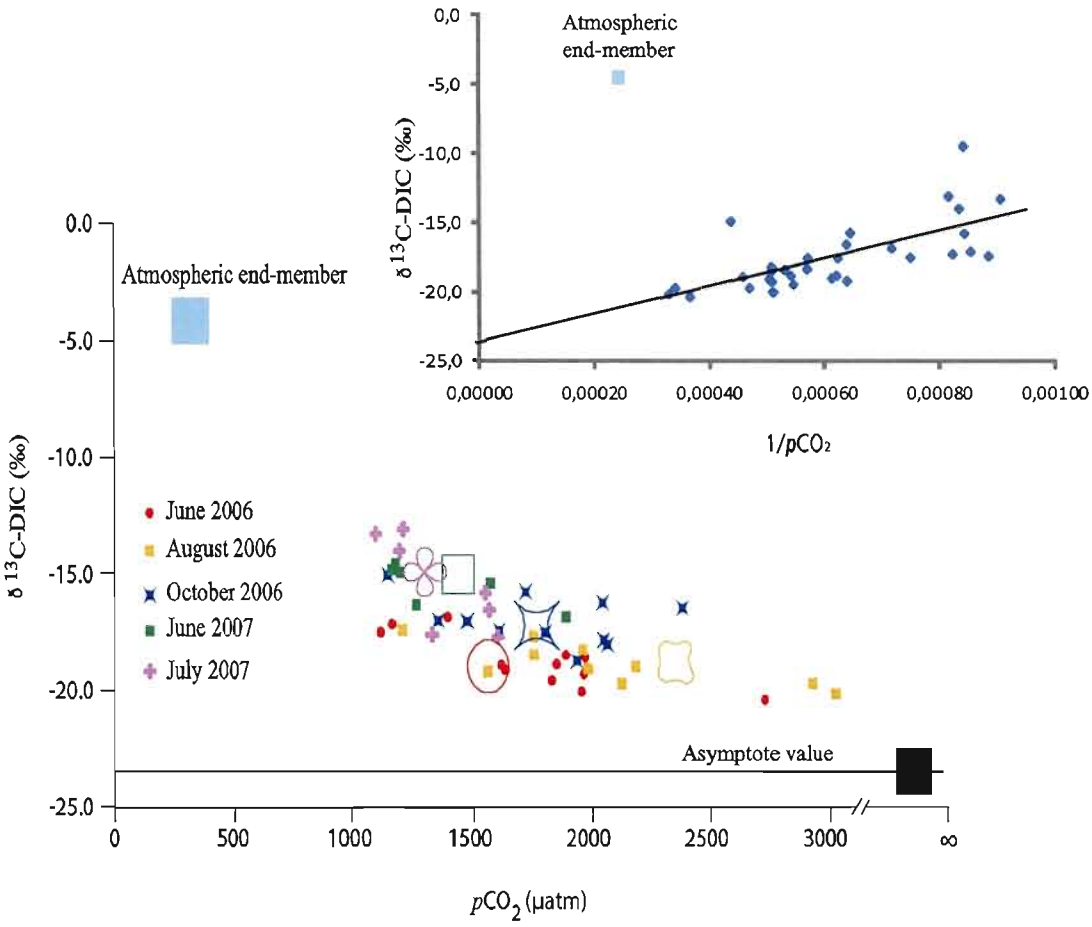

Figure 3. Correlations of δ^{13}C-DIC with pCO_2 and its inverse. Here, in the insert, we only use data from the warm water campaigns to estimate the assymptotic value of DIC produced in the reservoir (see text).

Two mechanisms can be involved in DOM oxidation: bacterial degradation and photochemical oxidation (Bertilsson and Tranvik, 2000; Hélie, 2004). These processes do not result in significant isotope fractionation (Hélie and Hillaire-Marcel, 2005). Consequently, the isotopic composition of the CO_2 produced by DOM oxidation can be described as:

[14] $\delta^{13}C\text{-}DIC = (f_{CO2\ dissolved} \cdot \delta^{13}C\text{-}CO_{2\ dissolved}) + (f_{HCO3} \cdot \delta^{13}C\text{-}HCO_3)$

where $f_{CO2\ dissolved}$ and $\delta^{13}C\text{-}CO_{2\ dissolved}$ are respectively the fraction and carbon isotopic composition of dissolved CO_2, f_{HCO3} and $\delta^{13}C\text{-}HCO_3$ are respectively the fraction and carbon isotopic composition of bicarbonate. Since carbonate ions can be neglected in view of the low pH measured in the reservoir, then:

[15] $f_{CO2\ dissolved} \sim 1 - f_{HCO3}$

Using relation [12], it is possible to calculate the separation factor between dissolved CO_2 and bicarbonate ($\varepsilon_{(CO2\text{-}HCO3)}$) and the bicarbonate proportion (% HCO_3) using relations [1] to [8]. Thus, $\delta^{13}C$ of DIC can be expressed as:

[16] $\delta^{13}C\text{-}DIC \sim \delta^{13}C\text{-}CO_{2\ dissolved} + (f_{HCO3} \cdot \varepsilon_{(CO2\text{-}HCO3)})$

Where $\delta^{13}C\text{-}CO_{2\ dissolved}$ is the average $\delta^{13}C$ of DOC measured at the surface of the reservoir. Since here, we assume that $CO_{2\ dissolved}$ is the result of DOM oxidation. Finally, the carbon isotopic composition of DIC produced by DOM oxidation can be expressed as:

[17] $\delta^{13}C\text{-}DIC \sim \delta^{13}C\text{-}DOC + (f_{HCO3} \cdot \varepsilon_{(CO2\text{-}HCO3)})$

Table 3 shows the calculated $\delta^{13}C$-DIC value that would result from DOM oxidation in comparison with the $\delta^{13}C$-DIC value observed from the Y-intercept of regression fit in Figure 3. Using the approach developed in Hélie and Hillaire-Marcel (2005), linking DIC-isotopic compositions to *in situ* CO_2-production rates from DOC oxidation vs. isotopic exchanges at the reservoir surface with atmospheric CO_2, this value suggest a mean

maximum production rate of CO_2, linked to DOC oxidation, of about 1 241 $mgCO_2*m^{-2}*d^{-1}$ throughout the sampling intervals (Table 4).

Table 3. Calculation of δ^{13}C-DIC insuing from DOM oxidation and comparison with δ^{13}C-DIC determined from Fig. 3 Y-intercepts for warm water campaigns

δ^{13}C-DOC (‰)	Water temp (°C)	$\varepsilon_{(CO2-HCO3)}$	% HCO_3	δ^{13}C-DIC calculated (‰)	δ^{13}C-DIC regression (‰)
-27.5 ± 0.2	13.9	10.39	30.7	-24.3 ± 0.6	-23.7 ± 1.0

Table 4. Mean CO_2 production rates linked to DOC oxidation.

	Sc_{CO2}	K_{600} $cm*hr^{-1}$	K_{CO2} $cm*hr^{-1}$	$[CO_2]sat$ $mmol*cm^{-3}$	$F_{eq\ atm}$ $mmol*m^{-2}*d^{-1}$	$F_{prod}/F_{eq\ atm}$	F_{prod} $mgCO_2*m^{-2}*d^{-1}$
Min	823.66	4.63	3.75	1.84×10^{-5}	15.95	0.72	1 013
Max	823.66	5.35	4.33	1.84×10^{-5}	19.54	0.72	1 241

4.3 Variability of carbon cycling in the Eastmain-1 reservoir

In detail, as illustrated on Figure 4, distinct linear relationships are observed, between δ^{13}C-DIC and the inverse of DIC concentrations, from each sampling campaign. Their Y-intercept values calculated from regression fits are reported in Table 5. During the warmest months (June 2006, August 2006 and July 2007 – when water temperatures are higher than 14°C), the isotopic compositions of DIC from DOC-oxidation are similar to those estimated from the Y-intercepts. During this period, the system is thus essentially governed by the CO_2 production from DOM oxidation in the water column, as it was the general case for the Robert-Bourassa reservoir (Hélie, 2004; Luther, 2000). From the available data, one cannot assess the relative weight of microbial respiration vs. photochemical reactions in DOM oxidation process. However, it has been demonstrated that boreal reservoirs, with their low pH and high lignin and fulvic substances contents, present favourable conditions for photooxidation (Anesio and Granéli, 2003; Bastien, 2005). Moreover, photodegradation and

biodegradation processes can interact closely. Ultraviolet radiation can degrade high molecular weight DOM, lignin and humic substances, which are recalcitrant to biodegradation, to low molecular weight DOM, which are biologically labile (Bertilsson and Tranvik, 2000). Thus, it is likely that both processes occur in the reservoir. Nevertheless, no increase in *p*CO2 was observed during the day compared to night-time measurements. We thus have no direct evidence of the impact of an enhanced photo-oxidation with day-light. This would suggest a relatively slow overall rate of DOM degradation, in agreement with its slow isotopic evolution highlighted above.

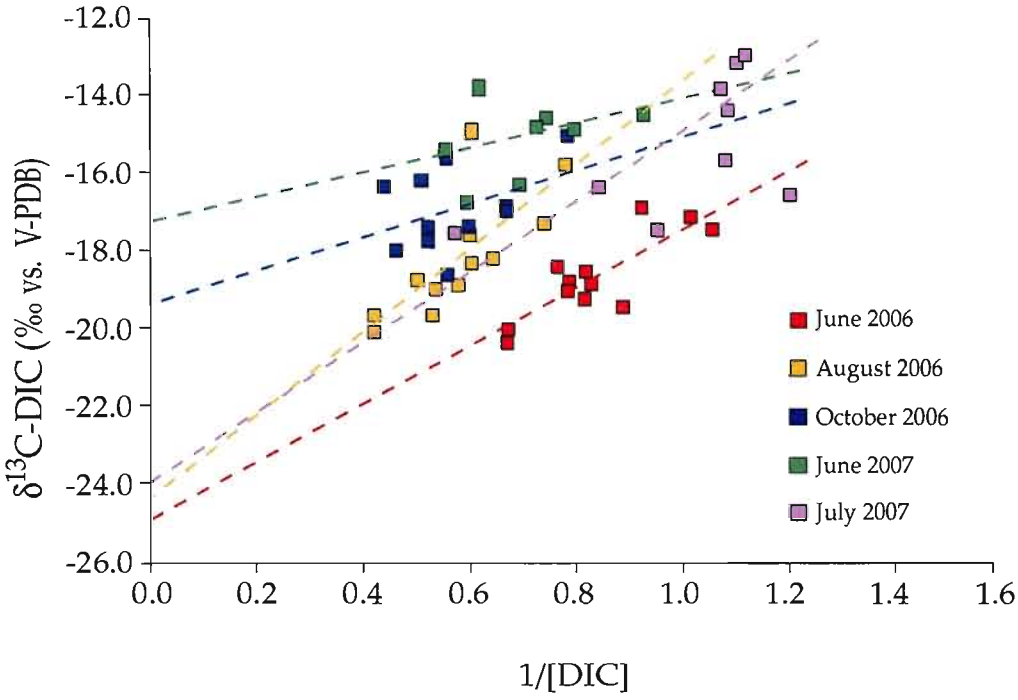

Figure 4. Correlations of δ^{13}C-DIC with the inverse of DIC.

Table 5. Calculation of δ^{13}C-DIC insuing from DOM oxidation and comparison with δ^{13}C-DIC determined from Figure 5 Y-intercepts (including standard deviations).

Campaign	δ^{13}C-DOC (‰)	Water temp (°C)	$\varepsilon_{(CO2\text{-}HCO3)}$	% HCO_3	δ^{13}C-DIC calculated (‰)	δ^{13}C-DIC regression (‰)
June 2006	-27.4 ± 0.4	14.9	10.29	25.7	-24.8 ± 0.9	-24.7 ± 1.6
August 2006	-27.4 ± 0.4	17.8	9.99	29.0	-24.5 ± 0.8	-25.1 ± 2.0
October 2006	-27.4 ± 0.4	10.4	10.82	31.9	-24.0 ± 0.8	-19.4 ± 1.8
June 2007	-27.7 ± 0.7	10.9	10.80	34.9	-23.9 ± 1.2	-17.5 ± 2.2
July 2007	-27.5 ± 0.2	15.0	10.27	32.7	-24.1 ± 0.5	-23.9 ± 2.7

Conversely, under colder conditions, i.e. in October 2006 and June 2007 where water temperatures are around 10°C, only mild correlations were observed between the Y-intercepts and δ^{13}C-DIC produced by DOM oxidation (Figure 4 and Table 5). For these cold months, however, a gradient of DIC concentrations and isotopic signatures was observed along the ancient Eastmain riverbed. DIC concentrations increased from the sampling site *Entrée-5* (at about 70 km), which is at the reservoir's inflow, towards the sampling site *Tour-1* (at about 9 km), located about 60 km away, near the reservoir's outlet (Figure 5). DIC production rates of 0.50 mg l^{-1} and 0.48 mg l^{-1} were respectively measured in October 2006 and June 2007. The residence time of water can be estimated based on the flow turbined at the hydroelectric plant. One can thus calculate a CO_2 production (in mg day^{-1}) in the "riverine" part of the reservoir (for more details see Table 6). Average productions of 7 823 mg of CO_2 m^{-2} day^{-1} in October 2006 and 551.7 mg of CO_2 m^{-2} day^{-1} in June 2007 are obtained. Blais (2006) measured CO_2 fluxes in this reservoir during the autumn 2006. In October, she observed emissions ranging from 3 911 to 17 350 mg of CO_2 m^{-2} day^{-1}, with an average value of 8 903 mg of CO_2 m^{-2} day^{-1} in agreement with estimates from this study. In a similar fashion, the isotopic signatures of DIC decreased from inflow to outflow during these cold intervals (Figure 5). A depletion in ^{13}C of 0.041‰ per km is observed in October 2006 and of 0.024‰ per km in June 2007. Thus suggesting, for these cold water campaigns, that ^{13}C-DIC values are not governed by *in situ* CO_2 production from DOM, but by degassing. These upstream-downstream gradients suggest a low inertia system, which reacts quickly to changes and behaves with a stream dynamics, in particular during intervals with a low residence time of water.

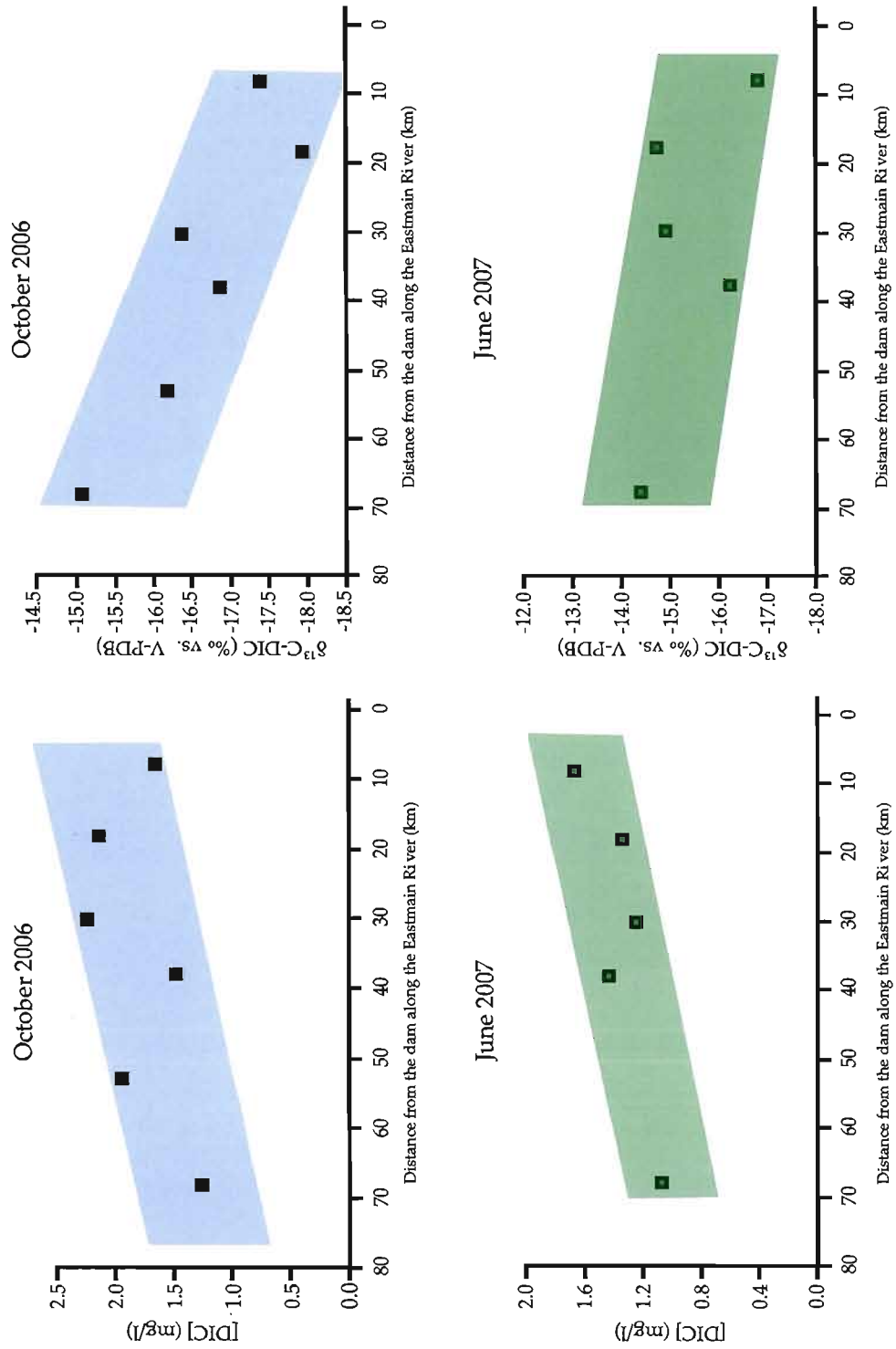

Figure 5. The δ^{13}C-DIC and DIC-concentration trends along the ancient Eastmain riverbed in October 2006 (blue) and June 2007 (green).

Table 6. Carbon and CO_2 production along the ancient Eastmain riverbed estimated from DIC-concentration rates.

October 2006

	River width (m)	Water volume (litre)	Area (m^2)	Flow ($m^3\ s^{-1}$)	Residence time (day)	[DIC] rate ($mg\ l^{-1}$)	$\delta^{13}C$-DIC fate (‰)	Prod. C ($mg\ l^{-1}\ d^{-1}$)	Prod. C ($mg\ d^{-1}$)	C fluxes ($mg\ m^{-2}\ d^{-1}$)	CO_2 fluxes ($mg\ m^{-2}\ d^{-1}$)
Max	35	5.17×10^{10}	2.38×10^{6}	364	2.0	0.498	-2.46	0.31	2.92×10^{10}	12 263	44 965
Min	3 500	8.57×10^{11}	2.38×10^{8}	341	29.0	0.498	-2.46	0.02	4.84×10^{11}	2 032	7 451
Average	1 768	4.54×10^{11}	1.20×10^{8}	348	15.0	0.498	-2.46	0.03	2.56×10^{11}	2 134	7 823

June 2007

	River width (m)	Water volume (litre)	Area (m^2)	Flow ($m^3\ s^{-1}$)	Residence time (day)	[DIC] rate ($mg\ l^{-1}$)	$\delta^{13}C$-DIC fate (‰)	Prod. C ($mg\ l^{-1}\ d^{-1}$)	Prod. C ($mg\ d^{-1}$)	C fluxes ($mg\ m^{-2}\ d^{-1}$)	CO_2 fluxes ($mg\ m^{-2}\ d^{-1}$)
Max	35	3.73×10^{10}	2.38×10^{6}	504	0.9	0.480	-1.41	0.533	1.99×10^{10}	8 361	30 656
Min	3 500	6.18×10^{11}	2.38×10^{8}	397	18.0	0.480	-1.41	0.027	1.65×10^{10}	69	254
Average	1 768	$3{,}28 \times 10^{11}$	1.20×10^{8}	434	8.7	0.480	-1.41	0.055	1.81×10^{10}	151	552

This is consistent with the physical and chemical characteristics of the reservoir. The shallow depth of this reservoir allows efficient mixing and homogenization of the water column, without a well-defined thermocline. Therefore, the absence of stratification and deep layers acting as buffers, leads to holomictic conditions. Under such conditions, the residence time of water and of DIC are relatively short, and hydraulicity plays a major role in the reservoir dynamics. This low-inertia system reacts quickly to variations in temperature conditions, wind stress, photosynthesis and exchanges with atmospheric CO_2, leading to a significant spatial and temporal variability of DIC concentrations and isotopic compositions, of CO_2 fluxes and hydraulicity. Both a decrease in temperature and/or residence time of DOC, and an increase in wind stress, produce DIC concentrations and isotopic composition closer to the atmospheric end-member (Figure 3), whereas, inversely, an increase of temperature and/or residence time of DOC, and a decrease in wind stress produce DIC concentrations and isotopic composition closer to the asymptotic value. These variations are well illustrated on Figure 3 as the points are scattered along the mixing curve. However, a slight temporal trend in $\delta\ ^{13}$C-DIC value, from 2006 to 2007 may suggest a trend toward steadier conditions following the high DOC-oxidation rates of the flooding period.

5. Conclusion

Stable carbon isotopes coupled to elemental analysis confirm features observed in other hydroelectric reservoirs (*e.g.*, Hélie, 2004): i) DOM is mainly from terrestrial origin in boreal reservoirs, and ii) its oxidation, in the water column, during warm period, accounts for CO_2 emissions at the surface of the reservoir. However, because of a much shorter residence time of DOC and water in the shallow reservoir Eastmain-1 compared to the deeper Robert-Bourassa reservoir, the model elaborated by Hélie and Hillaire-Marcel (2005) for estimating CO_2 fluxes at reservoir's surface from DIC isotopic compositions does not apply. Variations in physical and chemical properties of the reservoir water result in upstream-downstream gradient not unlike those which could be observed in a river system (*e.g.*, Hélie *et al.*, 2002). In comparison with larger reservoirs from the James Bay area, the Eastmain-1 reservoir does not seem to reach steady-state conditions at any time during the summer/fall seasons. This

property, more than the relative age of their impoundment, give them distinct features with respect to overall carbon cycling features.

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CONCLUSIONS

L'étude des isotopes stables du carbone couplée à des analyses élémentaires confirment les caractéristiques observées dans d'autres réservoirs hydroélectriques (*e.g.* Hélie, 2004) : i) la MOD des réservoirs boréaux a une origine majoritairement terrestre, et ii) son oxydation dans la colonne d'eau, durant les périodes chaudes, constitue le processus principal d'émissions de CO_2 à la surface du réservoir. Cependant, en raison du temps de séjour plus faible du COD et de l'eau dans le réservoir peu profond Eastmain-1, le modèle élaboré par Hélie et Hillaire-Marcel (2005) pour estimer les flux de CO_2 à la surface du réservoir à partir des compositions isotopiques du CID ne peut pas s'appliquer. La variation des propriétés physiques et chimiques de l'eau du réservoir entraîne la création de gradients amont-aval comparables de ceux qui peuvent être observés dans des systèmes fluviatiles (*e.g.* Hélie *et al.*, 2002). Comparativement aux réservoirs plus grands et plus âgés de la région de la Baie de James, le réservoir Eastmain-1 étant peu profond et possédant un faible temps de séjour de l'eau, ne semble pas atteindre des conditions d'équilibre à aucun moment durant les saisons étudiées (été/automne). Cette propriété, davantage que l'âge relatif à la mise en eau, permet d'établir plus distinctement les différences par rapport aux caractéristiques globales du cycle du carbone dans ces environnements.

APPENDICE A

TABLEAUX DES RÉSULTATS

ÉCHANTILLONNAGE DE SURFACE

June 2006

Sampling sites	Water column depth (m)	Air temp. (°C)	Wind speed ($m*s^{-1}$)	Water temp. (°C)	pH	Cond. ($\mu S*cm^{-1}$)	Alkalinity ($meq*l^{-1}$)	Dissolved oxygen content (%)	Dissolved oxygen content ($mg*l^{-1}$)	[POC] ($mg*l^{-1}$)	[DIC] ($mg*l^{-1}$)	[DOC] ($mg*l^{-1}$)
Tour-1 day	12.0	19.2	2.4	15.7	6.06	0.1	0.025	n.a	n.a	0.031	0.94	7.21
Tour-1 night	20.7	12.5	4.5	15.4	6.00	0.1	0.021	n.a	n.a	0.032	0.98	7.95
Riv-2	n.a	n.a	7.5	13.9	6.00	0.1	0.018	92.5	24.7	n.a	1.07	7.70
Riv-3	32.0	n.a	4.2	12.2	5.88	0.1	0.025	77.0	20.6	0.036	1.47	7.47
Riv-4	n.a	n.a	4.0	15.1	6.03	0.1	0.022	92.9	32.9	0.027	1.12	7.02
Entrée-5	22.0	n.a	4.1	17.0	6.05	0.1	0.032	43.1	11.4	0.043	1.26	6.22
B-6	n.a	15.0	3.5	14.6	6.10	0.1	0.021	94.2	32.9	n.a	1.20	7.79
Casey-7	n.a	n.a	3.4	15.0	6.00	0.1	0.037	96.2	29.8	0.020	1.21	7.59
B-8	n.a	n.a	5.8	13.7	5.72	0.1	0.022	80.2	22.6	n.a	1.48	7.90
B-9	n.a	n.a	5.1	15.2	6.10	0.1	n.a	95.2	32.9	0.028	1.21	7.31
B-10	n.a	21.5	2.5	16.5	5.92	0.1	0.026	n.a	n.a	0.030	1.26	7.07
Fed-11	15.3	15.8	3.9	14.3	5.95	0.1	0.028	59.3	13.5	n.a	1.29	7.46
Riv-12	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
Lac-13	n.a	21.7	1.3	17.9	6.46	0.1	0.024	n.a	n.a	0.051	0.72	7.82

June 2006

Sampling Sites	δ^{13}C-DIC (‰)	δ^{13}C-DOC (‰)	δ^{13}C-POC (‰)	C/N POM	C/N DOM	pCO_2 alk (µatm)	pCO_2 DIC (µatm)	pCO_2 GC (µatm)	$\delta^{13}CO_2$ atmospheric (‰)	$\delta^{13}CO_2$ aqueous (‰)
Tour-1 day	-17.46	-27.10	-28.94	10.36	52.46	1323	1094	1130	-12.35	-20.46
Tour-1 night	-17.13	n.a	-28.66	7.76	62.51	1422	1203	1171	n.a	-19.62
Riv-2	-16.90	-27.37	-28.08	n.a	57.26	1143	1264	1395	-13.83	-19.47
Riv-3	-20.00	-27.47	-27.41	12.72	57.54	1871	1752	1958	-11.01	-22.20
Riv-4	-19.44	-27.45	-27.18	12.46	37.89	1263	1320	1835	-13.52	-22.24
Entrée-5	-18.99	-27.37	-30.24	7.06	34.63	1678	2840	1633	-13.32	-22.05
B-6	-18.82	-27.38	-27.18	n.a	41.51	974	1318	1612	-16.87	-22.06
Casey-7	-19.23	-27.44	-29.09	10.75	50.49	2273	1464	1968	-12.44	-21.89
B-8	-20.33	-27.44	n.a	n.a	52.62	2656	1997	2729	-11.57	-21.86
B-9	-18.52	-27.64	-29.04	10.65	52.40	n.a	1328	1970	-15.96	n.a
B-10	-18.82	-27.43	-29.40	10.57	52.90	1958	1660	1849	-11.14	-21.15
Fed-11	-18.41	-27.47	-29.17	n.a	56.40	1957	1587	1891	-12.29	-20.80
Riv-12	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
Lac-13	-11.11	-27.66	-30.00	10.05	n.a	543	608	586	-12.48	-16.17

August 2006

Sampling sites	Water column depth (m)	Air temp. (°C)	Wind speed ($m*s^{-1}$)	Water temp. (°C)	pH	Cond. ($\mu S*cm^{-1}$)	Alkalinity ($meq*l^{-1}$)	Dissolved oxygen content (%)	Dissolved oxygen content ($mg*l^{-1}$)	[POC] ($mg*l^{-1}$)	[DIC] ($mg*l^{-1}$)	[DOC] ($mg*l^{-1}$)
Tour-1 day	16.0	18.0	6.2	17.2	6.09	12.0	0.036	80.3	7.7	0.032	1.27	6.21
Tour-1 night	15.9	12.9	2.9	16.6	6.00	11.0	0.065	107.4	10.4	0.034	1.33	6.35
Riv-2	40.0	12.9	5.6	17.8	6.08	11.0	0.049	86.5	36.9	0.041	n.a	n.a
Riv-3	30.5	13.0	3.3	17.3	6.07	12.0	0.039	81.1	35.9	0.043	1.63	5.98
Riv-4	11.0	18.1	7.4	17.4	6.10	12.0	0.042	75.8	7.3	0.046	1.54	5.95
Entrée-5	17.0	15.0	5.6	19.4	6.15	13.0	0.044	86.2	7.9	0.027	1.65	5.35
B-6	8.0	19.2	5.1	17.2	6.05	12.0	0.024	83.1	8.1	0.038	1.64	7.00
Casey-7	12.8	15.0	7.4	18.5	6.07	12.0	0.045	81.8	30.8	0.052	1.71	6.80
B-8	7.5	19.2	5.6	17.0	5.70	13.0	0.046	60.9	5.9	0.050	2.35	7.88
B-9	10.0	14.1	2.8	17.7	6.10	13.0	0.072	75.3	7.2	0.042	1.87	7.96
B-10	6.5	18.1	7.0	18.9	6.00	12.0	0.056	78.0	7.3	0.039	1.85	6.71
Fed-11	30.5	14.5	2.9	18.1	5.98	12.0	0.045	74.7	33.9	0.047	1.97	6.63
Riv-12	15.9	16.6	4.5	18.6	6.00	13.0	0.051	62.3	5.8	0.039	2.35	6.13
Lac-13	7.6	14.4	5.3	18.1	6.20	11.0	0.028	n.a	n.a	0.052	0.82	6.77

August 2006

Sampling sites	δ^{13}C-DIC (‰)	δ^{13}C-DOC (‰)	δ^{13}C-POC (‰)	C/N POM	C/N DOM	pCO_2 alk (µatm)	pCO_2 DIC (µatm)	pCO_2 GC (µatm)	$\delta^{13}CO_2$ atmospheric (‰)	$\delta^{13}CO_2$ aqueous (‰)
Tour-1 day	-15.82	-27.01	-29.84	9.75	46.86	1892	1641	1186	-16.29	-18.88
Tour-1 night	-17.31	n.a	-29.59	10.45	51.59	3387	1698	1216	-15.44	-20.36
Riv-2	-19.20	-27.68	-29.42	10.03	37.15	2591	n.a	1566	-13.94	-21.66
Riv-3	-14.95	-27.49	-29.21	9.49	48.67	2003	2122	2284	-15.45	-18.06
Riv-4	-18.21	-27.39	-29.93	9.94	46.52	2213	2013	1970	-15.88	-21.27
Entrée-5	-17.59	n.a	-29.49	9.53	39.10	2486	2311	1754	-14.88	-20.56
B-6	-18.35	-27.21	-29.97	9.15	48.35	1177	2101	1758	-15.03	-21.56
Casey-7	-18.92	-27.49	-31.66	9.00	47.00	2749	1780	2183	n.a	-21.44
B-8	-20.14	-27.60	n.a	n.a	51.47	5045	3686	3030	-15.89	-21.88
B-9	-19.70	-27.34	n.a	9.59	39.39	3245	2363	2130	-14.41	-23.11
B-10	-19.05	-27.58	-29.46	10.26	38.80	2999	2521	1984	n.a	-22.11
Fed-11	-18.78	-27.48	-30.65	9.09	47.27	2813	2788	n.a	-15.21	-21.51
Riv-12	-19.69	-27.20	-29.18	9.55	38.59	3068	3346	2933	-14.46	-22.52
Lac-13	-5.18	-27.27	-30.86	10.69	60.46	1238	997	n.a	-13.43	-8.64

October 2006

Sampling sites	Water column depth (m)	Air temp. (°C)	Wind speed ($m*s^{-1}$)	Water temp. (°C)	pH	Cond. ($\mu S*cm^{-1}$)	Alkalinity ($meq*l^{-1}$)	Dissolved oxygen content (%)	Dissolved oxygen content ($mg*l^{-1}$)	[POC] ($mg*l^{-1}$)	[DIC] ($mg*l^{-1}$)	[DOC] ($mg*l^{-1}$)
Tour-1 day	17.3	5.7	5.0	10.6	6.18	17.0	0.030	100.6	10.6	0.030	1.65	7.01
Riv-2	34.5	9.8	5.1	10.8	6.21	17.0	0.121	85.6	9.4	0.014	2.14	7.02
Riv-3	21.1	10.0	7.1	11.0	6.10	17.0	0.131	104.2	11.3	0.009	2.24	6.87
Riv-4	13.0	5.9	4.8	10.6	6.24	17.0	0.047	99.7	10.4	0.016	1.47	6.81
Entrée-5	21.5	2.3	4.5	10.3	6.22	16.0	0.046	98.5	10.8	0.015	1.26	6.47
B-6	9.5	5.7	3.6	10.4	6.00	17.0	0.041	95.1	10.0	0.014	1.76	6.96
Casey-7	14.2	5.2	4.8	10.3	6.12	17.0	0.058	94.1	9.7	0.019	1.47	7.00
B-8	6.0	9.8	4.8	9.8	6.00	16.0	0.076	102.2	10.9	0.025	1.89	8.25
B-9	12.7	9.7	5.6	9.9	6.17	17.0	0.087	101.4	11.1	0.015	1.78	7.31
B-10	8.0	5.0	5.4	10.0	6.15	16.0	n.a	89.9	10.1	n.a	n.a	n.a
Fed-11	12.7	9.8	6.6	10.5	6.21	18.0	0.107	103.4	10.8	0.017	1.89	7.26
Riv-12	24.7	9.7	6.8	10.5	6.08	16.0	0.105	90.8	10.0	0.021	1.94	6.84
Lac-13	8.0	13.7	4.0	9.2	6.44	15.0	0.021	101.4	11.3	0.015	0.82	6.74

October 2006

Sampling sites	δ^{13}C-DIC (‰)	δ^{13}C-DOC (‰)	δ^{13}C-POC (‰)	C/N POM	C/N DOM	pCO_2 alk (µatm)	pCO_2 DIC (µatm)	pCO_2 GC (µatm)	$\delta^{13}CO_2$ atmospheric (‰)	$\delta^{13}CO_2$ aqueous (‰)
Tour-1 day	-17.40	-27.45	-28.30	9.08	34.57	1081	1610	n.a	n.a	-21.09
Riv-2	-17.94	-27.33	-28.89	7.87	35.74	4079	2068	n.a	-14.32	-21.80
Riv-3	-16.35	-27.72	-28.87	8.52	36.53	5701	2376	n.a	-14.71	-19.61
Riv-4	-16.86	-27.39	-28.10	9.26	33.56	1475	1358	n.a	-15.31	-20.89
Entrée-5	-15.05	-27.49	-28.67	8.37	40.55	1507	1157	n.a	-15.08	-18.96
B-6	-18.63	-27.59	-28.16	8.63	36.51	2231	1939	n.a	-15.43	-21.38
Casey-7	-16.95	-27.53	-28.01	7.91	30.52	2391	1480	n.a	-13.79	-20.31
B-8	-17.75	-27.34	-28.41	7.13	36.88	4109	2047	n.a	-14.02	-20.50
B-9	-15.62	-27.35	-31.64	8.43	30.20	3183	1719	n.a	n.a	-19.24
B-10	-16.10	n.a	n.a	n.a	n.a	n.a	n.a	n.a	-13.96	n.a
Fed-11	-17.37	-27.46	-29.30	8.89	33.70	3596	1802	n.a	-14.32	-21.22
Riv-12	-16.18	-27.16	-29.12	8.24	40.19	4760	2042	n.a	n.a	-19.33
Lac-13	-12.82	-27.56	-29.98	10.18	39.17	409	573	n.a	-13.94	-18.06

June 2007

Sampling sites	Water column depth (m)	Air temp. (°C)	Wind speed ($m*s^{-1}$)	Water temp. (°C)	pH	Cond. ($\mu S*cm^{-1}$)	Alkalinity ($meq*l^{-1}$)	Dissolved oxygen content (%)	Dissolved oxygen content ($mg*l^{-1}$)	[POC] ($mg*l^{-1}$)	[DIC] ($mg*l^{-1}$)	[DOC] ($mg*l^{-1}$)
Tour-1 day	7.5	3.8	2.8	7.4	5.93	n.a	0.064	98.9	10.6	0.056	1.67	5.71
Riv-2	32.3	6.8	3.2	9.5	6.14	n.a	0.039	115.3	12.1	0.052	1.33	5.59
Riv-3	17.9	7.9	3.8	10.4	6.19	n.a	0.037	116.0	11.9	0.057	1.24	5.85
Riv-4	10.3	7.8	0.3	10.4	6.22	n.a	0.030	117.7	12.1	0.043	1.42	5.76
Entrée-5	15.7	11.8	5.5	13.1	6.24	n.a	0.034	109.0	11.1	0.049	1.07	5.49
B-6	2.6	10.7	2.0	10.4	6.24	n.a	0.036	125.7	12.9	0.071	1.36	5.87
B-8	6.0	6.0	4.2	11.3	6.22	n.a	0.050	108.1	10.7	0.081	1.79	6.13
Fed-11	9.0	7.2	3.6	11.7	6.34	n.a	0.066	122.3	11.9	0.077	1.60	6.11
Lac-13	n.a	n.a	n.a	14.0	6.30	11.0	0.041	n.a	n.a	0.036	0.91	6.81

June 2007

Sampling sites	δ^{13}C-DIC (‰)	δ^{13}C-DOC (‰)	δ^{13}C-POC (‰)	C/N POM	C/N DOM	pCO_2 alk (µatm)	pCO_2 DIC (µatm)	pCO_2 GC (µatm)	$\delta^{13}CO_2$ atmospheric (‰)	$\delta^{13}CO_2$ aqueous (‰)
Tour-1 day	-16.82	-27.61	-29.55	11.33	37.51	3964	1838	1893	-11.09	-19.20
Riv-2	-14.62	-27.89	-29.40	10.79	42.64	1523	1367	1193	-10.04	-18.08
Riv-3	-14.90	-27.55	-30.52	10.84	44.60	1300	1258	1176	-11.74	-18.64
Riv-4	-16.31	-27.33	-28.72	11.68	44.99	984	1406	1276	-11.88	-20.22
Entrée-5	-14.49	n.a	-30.47	10.54	n.a	1098	1110	n.a	-10.57	-18.54
B-6	-14.87	-27.77	-28.98	12.97	39.91	1128	1321	1204	-11.95	-16.92
Casey-7	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
B-8	-15.45	-27.86	-31.07	9.70	36.61	1656	1812	1581	-11.73	-19.36
B-9	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
B-10	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
Fed-11	-13.83	n.a	-33.30	8.70	31.68	1666	1461	1171	-11.81	-16.74
Riv-12	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
Lac-13	-11.04	-27.69	-28.32	11.96	39.92	1166	914	848	n.a	-15.44

July 2007

Sampling sites	Water column depth (m)	Air temp (°C)	Wind speed ($m*s^{-1}$)	Water temp. (°C)	pH	Cond. ($\mu S*cm^{-1}$)	Alkalinity ($meq*l^{-1}$)	Dissolved oxygen content (%)	Dissolved oxygen content ($mg*l^{-1}$)	[POC] ($mg*l^{-1}$)	[DIC] ($mg*l^{-1}$)	[DOC] ($mg*l^{-1}$)
Tour-1 day	9.0	20.4	2.2	17.7	6.32	n.a	0.042	96.9	n.a	n.a	0.90	6.16
Riv-2	26.4	16.7	5.1	15.5	6.18	n.a	0.031	91.1	n.a	n.a	0.89	6.12
Riv-3	19.2	13.8	2.3	14.2	6.20	n.a	0.046	92.4	n.a	n.a	1.04	6.33
Riv-4	11.7	17.6	1.7	15.6	6.38	n.a	0.041	102.2	n.a	n.a	0.68	6.36
Entrée-5	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	0.91	5.75
B-6	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	0.85	6.10
Casey-7	12.4	16.1	2.1	15.1	6.28	n.a	0.046	91.6	n.a	n.a	0.92	6.72
B-8	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	1.17	6.76
B-9	10.1	15.2	2.8	14.5	6.02	n.a	0.042	91.1	n.a	n.a	0.82	6.66
B-10	7.5	14.3	2.7	13.4	5.63	n.a	0.022	88.7	n.a	n.a	0.92	6.91
Fed-11	12.8	16.5	2.0	14.1	5.57	n.a	0.022	93.1	n.a	n.a	1.72	6.26
Riv-12	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	1.23	6.26
Lac-13	6.4	15.5	4.2	13.4	5.66	n.a	0.010	94.3	n.a	n.a	0.67	6.42

July 2007

Sampling sites	δ^{13}C-DIC (‰)	δ^{13}C-DOC (‰)	δ^{13}C-POC (‰)	C/N POM	C/N DOM	pCO_2 alk (µatm)	pCO_2 DIC (µatm)	pCO_2 GC (µatm)	$\delta^{13}CO_2$ atmospheric (‰)	$\delta^{13}CO_2$ aqueous (‰)
Tour-1 day	-13.26	n.a	n.a	n.a	n.a	1189	963	1103	n.a	-17.76
Riv-2	-13.08	n.a	n.a	n.a	n.a	1200	1027	1223	n.a	-16.80
Riv-3	-17.55	n.a	n.a	n.a	n.a	1663	1147	1334	n.a	-21.38
Riv-4	-9.54	n.a	n.a	n.a	n.a	989	655	1187	n.a	-14.40
Entrée-5	-14.51	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
B-6	-11.47	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
Casey-7	-13.98	n.a	n.a	n.a	n.a	1396	970	1197	n.a	-18.26
B-8	-16.45	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
B-9	-16.62	n.a	n.a	n.a	n.a	2305	1047	1568	n.a	-19.51
B-10	-15.77	n.a	n.a	n.a	n.a	2961	1356	1552	n.a	-17.18
Fed-11	-17.59	n.a	n.a	n.a	n.a	3360	2650	1606	n.a	-18.84
Riv-12	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
Lac-13	-10.04	n.a	n.a	n.a	n.a	1172	974	519	n.a	-11.53

APPENDICE B

TABLEAUX DES RÉSULTATS

ÉCHANTILLONNAGE EN PROFONDEUR (COLONNES D'EAU)

June 2006

Tour-1 day sampling

Depth (m)	Water temp. (°C)	pH	Cond. ($\mu S*cm^{-1}$)	Alkalinity ($meq*l^{-1}$)	[POC] ($mg*l^{-1}$)	[DIC] ($mg*l^{-1}$)	[DOC] ($mg*l^{-1}$)	$\delta^{13}C$-DIC (‰)	$\delta^{13}C$-DOC (‰)	$\delta^{13}C$-POC (‰)	C/N POM	C/N DOM	pCO_2 alk (µatm)	pCO_2 DIC (µatm)	pCO_2 GC (µatm)	$\delta^{13}CO_2$ aqueous (‰)
0	15.7	6.06	0.1	0.025	0.031	0.94	7.21	-17.60	-27.11	-28.94	10.39	50.39	1261	626	1130	-20.70
2	15.7	6.07	0.1	0.043	0.039	0.99	7.61	-17.64	-27.27	-28.94	11.25	48.71	2119	707	1187	-20.79
4	15.7	6.07	0.1	0.025	0.028	1.03	7.33	-18.29	-27.04	-28.31	10.30	41.30	1232	790	n.a	-21.44
5	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	1269	n.a
6	14.0	5.95	0.1	0.025	0.030	1.12	7.48	-19.36	-27.07	-27.60	10.30	52.85	1591	1020	n.a	-21.93
8	13.7	5.95	0.1	0.024	0.030	1.01	7.77	-18.61	-27.17	-27.09	9.85	49.82	1522	975	n.a	-21.18
10	13.6	5.91	0.1	0.019	0.031	0.98	7.42	-18.83	-27.19	-27.06	9.63	47.52	1320	1030	1156	-21.22
12	13.4	5.89	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
14	13.3	5.83	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
16	13.3	5.84	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a

June 2006

Tour-1 night sampling

Depth (m)	Water temp. (°C)	pH	Cond. ($\mu S*cm^{-1}$)	Alkalinity ($meq*l^{-1}$)	[POC] ($mg*l^{-1}$)	[DIC] ($mg*l^{-1}$)	[DOC] ($mg*l^{-1}$)	$\delta^{13}C$-DIC (‰)	$\delta^{13}C$-DOC (‰)	$\delta^{13}C$-POC (‰)	C/N POM	C/N DOM	pCO_2 alk (μatm)	pCO_2 DIC (μatm)	pCO_2 GC (μatm)	$\delta^{13}CO_2$ aqueous (‰)
0	15.4	6.00	0.1	0.021	0.032	0.98	7.95	-17.13	-27.04	-28.66	7.76	62.51	1211	682	1171	-19.93
2	15.4	6.10	0.1	0.079	0.036	0.98	7.55	-15.73	-27.04	-28.47	9.19	53.90	1489	688	1176	-19.03
4	15.3	6.05	0.1	0.029	n.a	1.04	7.33	-17.07	-26.99	-28.44	n.a	45.01	1489	817	n.a	-20.12
6	15.2	6.03	0.1	0.023	n.a	0.99	7.11	-17.59	-27.08	-28.30	n.a	52.85	1235	842	n.a	-20.54
8	14.3	5.95	0.1	0.025	n.a	0.93	7.18	-17.25	-27.12	-28.85	n.a	52.00	1597	889	n.a	-19.82
10	13.3	5.88	0.1	0.024	0.032	1.17	7.17	-18.77	-27.01	-27.55	10.90	58.28	1779	1276	1421	-21.03
12	12.6	5.92	0.1	0.030	0.03	1.39	7.63	-19.79	-27.02	-27.37	10.96	58.53	2012	1607	n.a	-22.21
14	10.6	5.69	0.1	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
16	8.2	5.54	0.1	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
18	7.0	5.56	0.1	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a

June 2006

Entrée-5

Depth (m)	Water temp. (°C)	pH	Cond. ($\mu S*cm^{-1}$)	Alkalinity ($meq*l^{-1}$)	[POC] ($mg*l^{-1}$)	[DIC] ($mg*l^{-1}$)	[DOC] ($mg*l^{-1}$)	$\delta^{13}C$-DIC (‰)	$\delta^{13}C$-DOC (‰)	$\delta^{13}C$-POC (‰)	C/N POM	C/N DOM	pCO_2 alk (μatm)	pCO_2 DIC (μatm)	pCO_2 GC (μatm)	$\delta^{13}CO_2$ aqueous (‰)
0	17.0	6.05	0.1	0.032	0.043	2.28	6.22	-18.99	-27.37	-30.24	7.06	34.63	1677	1591	n.a	-22,05
1	17.0	6.03	0.1	0.040	0.052	n.a	n.a	-18.75	-27.33	-29.06	8.81	31.36	2196	n.a	n.a	-21,71
2	17.0	6.04	0.1	0.032	0.043	1.30	6.14	-17.82	-27.32	-29.41	9.00	40.38	1717	957	n.a	-20,83
3	17.0	6.02	0.1	0.030	0.034	1.41	6.47	-19.13	-27.48	-29.30	9.30	42.14	1685	1098	n.a	-22,04
4	17.0	6.03	0.1	0.044	0.031	1.47	6.65	-17.64	-27.34	-29.05	10.06	37.66	2415	1182	n.a	-20,60
5	17.0	6.00	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a

June 2006

Casey-7

Depth (m)	Water temperature (°C)	pH	Conductivity ($\mu S*cm^{-1}$)	Alkalinity ($meq*l^{-1}$)	[POC] ($mg*l^{-1}$)	[DIC] ($mg*l^{-1}$)	[DOC] ($mg*l^{-1}$)	C/N POM	C/N DOM
0	15.0	6.00	0.1	0.037	0.020	1.21	7.59	10.75	50.49
1	15.1	6.03	0.1	0.029	0.040	1.12	7.77	10.50	47.82
2	15.1	6.00	0.1	0.019	0.027	1.18	7.53	8.79	53.71
3	15.1	6.00	0.1	0.028	0.027	1.12	8.70	9.08	44.40
4	15.1	6.02	0.1	0.016	0.027	1.21	7.20	9.15	50.66
5	15.1	6.01	0.1	n.a	n.a	n.a	n.a	n.a	n.a

Depth (m)	δ^{13}C-DIC (‰)	δ^{13}C-DOC (‰)	δ^{13}C-POC (‰)	pCO_2 alk (µatm)	pCO_2 DIC (µatm)	pCO_2 GC (µatm)	$\delta^{13}CO_2$ aqueous (‰)	Dissolved oxygen content (%)	Dissolved oxygen content ($mg*l^{-1}$)
0	-19.23	-27.44	-29.09	2124	860	n.a	-22.03	96.2	29.8
1	-18.44	-27.47	-28.40	1556	806	n.a	-21.39	95.8	28.8
2	-19.24	-27.43	-28.95	1092	896	n.a	-22.04	93.8	28.3
3	-18.85	-27.49	-28.56	1609	880	n.a	-21.65	91.9	28.8
4	-19.54	-27.44	-29.31	878	980	n.a	-22.44	91.7	28.8
5	n.a	n.a	n.a	n.a	n.a	n.a	n.a	93.9	28.8

August 2006

Tour-1 day sampling

Depth (m)	Water temperature (°C)	pH	Conductivity ($\mu S*cm^{-1}$)	Alkalinity ($meq*l^{-1}$)	[POC] ($mg*l^{-1}$)	[DIC] ($mg*l^{-1}$)	[DOC] ($mg*l^{-1}$)	C/N POM	C/N DOM
0	17.2	6.09	12.0	0.036	0.032	1.27	6.21	9.75	46.86
2	17.2	6.12	12.0	0.049	0.033	1.30	6.84	10.76	47.77
5	17.2	6.11	12.0	0.039	0.033	1.41	6.35	11.01	53.13
6	17.0	6.11	12.0	n.a	n.a	n.a	n.a	n.a	n.a
8	17.0	6.10	12.0	n.a	n.a	n.a	n.a	n.a	n.a
10	16.9	6.08	12.0	0.031	0.033	1.43	6.29	10.00	32.33
12	16.8	6.04	12.0	n.a	n.a	n.a	n.a	n.a	n.a

Depth (m)	δ^{13}C-DIC (‰)	δ^{13}C-DOC (‰)	δ^{13}C-POC (‰)	pCO_2 alk (µatm)	pCO_2 DIC (µatm)	pCO_2 GC (µatm)	$\delta^{13}CO_2$ aqueous (‰)	Dissolved oxygen content (%)	Dissolved oxygen content ($mg*l^{-1}$)
0	-15.82	-27.01	-29.84	1724	887	1186	n.a	80.3	7.7
2	-16.91	-27.08	-28.92	2190	961	1238	n.a	77.7	7.5
5	-18.27	-27.03	-29.14	1784	1173	1354	-21.63	77.1	7.5
6	n.a	n.a	n.a	n.a	n.a	n.a	n.a	76.4	7.4
8	n.a	n.a	n.a	n.a	n.a	n.a	n.a	76.0	7.4
10	-18.34	-27.30	-28.67	1515	1445	1280	-21.54	74.4	7.2
12	n.a	n.a	n.a	n.a	n.a	n.a	n.a	73.1	7.1

August 2006

Tour-1 night sampling

Depth (m)	Water temperature (°C)	pH	Conductivity ($\mu S*cm^{-1}$)	Alkalinity ($meq*l^{-1}$)	[POC] ($mg*l^{-1}$)	[DIC] ($mg*l^{-1}$)	[DOC] ($mg*l^{-1}$)	C/N POM	C/N DOM
0	16.6	6.00	11.0	0.065	0.034	1.33	6.35	10.45	51.59
2	16.3	5.99	11.0	0.028	0.035	n.a	n.a	10.60	51.68
4	16.3	5.99	11.0	n.a	n.a	n.a	n.a	n.a	n.a
5	16.3	5.99	11.0	0.036	0.041	1.28	6.49	9.39	n.a
6	16.3	5.98	11.0	n.a	n.a	n.a	n.a	n.a	n.a
8	16.3	5.98	11.0	n.a	n.a	n.a	n.a	n.a	n.a
10	16.4	5.96	11.0	0.026	0.035	1.39	7.17	9.86	45.56
12	16.3	5.86	12.0	n.a	n.a	n.a	n.a	n.a	n.a

Depth (m)	δ^{13}C-DIC (‰)	δ^{13}C-DOC (‰)	δ^{13}C-POC (‰)	pCO_2 alk (μatm)	pCO_2 DIC (μatm)	pCO_2 GC (μatm)	$\delta^{13}CO_2$ aqueous (‰)	Dissolved oxygen content (%)	Dissolved oxygen content ($mg*l^{-1}$)
0	-17.31	-27.50	-29.59	3802	999	1216	-20.13	107.4	10.4
2	-18.79	-27.36	-29.96	1671	993	1212	-21.55	103.4	10.1
4	n.a	n.a	n.a	n.a	n.a	n.a	n.a	103.1	10.1
5	-18.52	n.a	-30.17	2148	1150	n.a	-21.29	103.3	10.1
6	n.a	n.a	n.a	n.a	n.a	n.a	n.a	103.3	10.1
8	n.a	n.a	n.a	n.a	n.a	n.a	n.a	103.5	10.1
10	-15.65	-27.29	-29.29	1665	1522	1571	n.a	103.0	10.0
12	n.a	n.a	n.a	n.a	n.a	n.a	n.a	101.2	9.9

August 2006

Entrée-5

Depth (m)	Water temperature (°C)	pH	Conductivity ($\mu S*cm^{-1}$)	Alkalinity ($meq*l^{-1}$)	[POC] ($mg*l^{-1}$)	[DIC] ($mg*l^{-1}$)	[DOC] ($mg*l^{-1}$)	C/N POM	C/N DOM
0	19.4	6.15	13.0	0.044	0.027	1.65	5.35	9.53	39.10
2	19.4	6.15	13.0	0.019	0.028	1.29	5.84	9.78	37.07
5	19.3	6.15	13.0	0.040	0.039	1.57	5.52	10.27	39.77
10	19.3	6.13	13.0	0.057	0.028	1.75	5.68	9.70	40.51
12	19.1	6.13	13.0	n.a	n.a	n.a	n.a	n.a	n.a
14	19.0	6.14	13.0	n.a	n.a	n.a	n.a	n.a	n.a
16	18.8	6.11	13.0	n.a	n.a	n.a	n.a	n.a	n.a

Depth (m)	δ^{13}C-DIC (‰)	δ^{13}C-DOC (‰)	δ^{13}C-POC (‰)	pCO_2 alk (µatm)	pCO_2 DIC (µatm)	pCO_2 GC (µatm)	$\delta^{13}CO_2$ aqueous (‰)	Dissolved oxygen content (%)	Dissolved oxygen content ($mg*l^{-1}$)
0	-17.59	-27.25	-29.49	1887	1099	n.a	-21.15	86.2	7.9
2	-17.38	-27.20	-29.36	815	822	n.a	-20.95	86.8	8.0
5	-17.75	-27.04	-29.14	1713	1124	n.a	-21.32	85.5	7.9
10	-16.24	-27.19	-29.70	2558	1512	n.a	-19.70	83.8	7.7
12	n.a	n.a	n.a	n.a	n.a	n.a	n.a	81.8	7.6
14	n.a	n.a	n.a	n.a	n.a	n.a	n.a	80.7	7.5
16	n.a	n.a	n.a	n.a	n.a	n.a	n.a	79.1	7.4

August 2006

Casey-7

Depth (m)	Water temperature (°C)	pH	Conductivity ($\mu S*cm^{-1}$)	Alkalinity ($meq*l^{-1}$)	[POC] ($mg*l^{-1}$)	[DIC] ($mg*l^{-1}$)	[DOC] ($mg*l^{-1}$)	C/N POM	C/N DOM
0	18.5	6.07	12.0	0.045	0.052	1.71	6.80	9.00	47.00
2	18.3	6.07	12.0	0.051	0.047	1.62	6.90	9.58	40.99
4	18.3	6.06	12.0	0.053	0.056	2.07	7.83	9.93	37.53
6	18.3	6.02	12.0	0.050	0.047	1.55	6.97	9.53	44.03
8	18.5	6.00	12.0	0.041	0.053	1.92	7.11	8.85	47.14
10	18.1	5.83	13.0	0.039	0.050	2.36	8.30	8.98	49.44

Depth (m)	δ^{13}C-DIC (‰)	δ^{13}C-DOC (‰)	δ^{13}C-POC (‰)	pCO_2 alk (μatm)	pCO_2 DIC (μatm)	pCO_2 GC (μatm)	$\delta^{13}CO_2$ aqueous (‰)	Dissolved oxygen content (%)	Dissolved oxygen content ($mg*l^{-1}$)
0	-18.92	-27.49	-31.66	2295	1094	n.a	-22.08	81.8	30.8
2	-18.11	-27.52	-29.44	2596	1115	n.a	-21.27	82.3	30.8
4	-13.18	-27.57	-29.77	2760	1554	n.a	-16.29	82.4	30.8
6	-18.60	-27.63	-30.14	2856	1271	n.a	-21.51	81.3	30.8
8	-17.44	-27.69	-30.02	2457	1726	n.a	-20.27	80.6	30.8
10	-16.15	-27.59	-30.42	3439	2521	n.a	n.a	72.5	30.8

October 2006

Tour-1 day sampling

Depth (m)	Water temperature (°C)	pH	Conductivity ($\mu S*cm^{-1}$)	Alkalinity ($meq*l^{-1}$)	[POC] ($mg*l^{-1}$)	[DIC] ($mg*l^{-1}$)	[DOC] ($mg*l^{-1}$)	C/N POM	C/N DOM
0	10.6	6.18	17.0	0.030	0.030	1.65	7.01	9.08	34.57
2	10.5	6.12	17.0	0.030	0.035	1.50	6.97	10.02	34.90
5	10.6	6.15	17.0	0.062	0.029	1.69	7.02	9.38	34.41
10	10.6	6.13	17.0	0.052	0.029	1.64	7.00	8.88	36.26

Depth (m)	δ^{13}C-DIC (‰)	δ^{13}C-DOC (‰)	δ^{13}C-POC (‰)	pCO_2 alk (µatm)	pCO_2 DIC (µatm)	pCO_2 GC (µatm)	$\delta^{13}CO_2$ aqueous (‰)	Dissolved oxygen content (%)	Dissolved oxygen content ($mg*l^{-1}$)
0	-17.40	-27.45	-28.30	1081	1110	n.a	-21.09	100.6	10.6
2	-16.58	-27.47	-27.98	1241	1128	n.a	-19.94	79.5	8.9
5	-18.52	-27.47	-27.26	2394	1390	n.a	-22.04	71.4	8.9
10	-17.43	-27.64	-28.10	2103	1626	n.a	-20.84	79.4	8.9

October 2006

Entrée-5

Depth (m)	Water temperature (°C)	pH	Conductivity ($\mu S*cm^{-1}$)	Alkalinity ($meq*l^{-1}$)	[POC] ($mg*l^{-1}$)	[DIC] ($mg*l^{-1}$)	[DOC] ($mg*l^{-1}$)	C/N POM	C/N DOM
0	10.3	6.22	n.a	0.046	0.015	1.26	6.47	8.37	40.55
2	10.3	6.20	n.a	0.030	0.023	1.28	6.60	8.07	41.31
5	10.3	6.20	n.a	0.046	0.023	1.32	6.42	8.25	37.53
10	10.2	6.20	n.a	0.052	0.018	1.41	6.47	8.47	34.96

Depth (m)	$\delta^{13}C$-DIC (‰)	$\delta^{13}C$-DOC (‰)	$\delta^{13}C$-POC (‰)	pCO_2 alk (µatm)	pCO_2 DIC (µatm)	pCO_2 GC (µatm)	$\delta^{13}CO_2$ aqueous (‰)	Dissolved oxygen content (%)	Dissolved oxygen content ($mg*l^{-1}$)
0	-15.05	-27.49	-28.67	1507	806	n.a	-18,96	n.a	n.a
2	-16.01	-27.44	-28.51	1029	900	n.a	-19,80	n.a	n.a
5	-22.44	-27.86	-28.21	1578	1032	n.a	-26,23	n.a	n.a
10	-16.78	-27.25	-28.22	1782	1323	n.a	n.a	n.a	n.a

October 2006

Casey-7

Depth (m)	Water temperature (°C)	pH	Conductivity ($\mu S*cm^{-1}$)	Alkalinity ($meq*l^{-1}$)	[POC] ($mg*l^{-1}$)	[DIC] ($mg*l^{-1}$)	[DOC] ($mg*l^{-1}$)	C/N POM	C/N DOM
0	10.3	6.12	n.a	0.058	0.019	1.47	7.00	7.91	30.52
2	10.3	6.10	n.a	0.033	0.018	n.a	n.a	7.57	30.53
5	10.3	6.14	n.a	0.140	0.012	2.12	7.09	8.43	28.87
10	10.3	6.10	n.a	0.059	0.014	1.59	7.10	7.82	29.29

Depth (m)	δ^{13}C-DIC (‰)	δ^{13}C-DOC (‰)	δ^{13}C-POC (‰)	pCO_2 alk (µatm)	pCO_2 DIC (µatm)	pCO_2 GC (µatm)	$\delta^{13}CO_2$ aqueous (‰)	Dissolved oxygen content (%)	Dissolved oxygen content ($mg*l^{-1}$)
0	-16.95	-27.53	-28.01	2391	1032	n.a	-20.31	n.a	n.a
2	-17.68	-27.90	-28.35	1425	n.a	n.a	-20.93	n.a	n.a
5	-17.53	-27.39	-28.54	5512	1780	n.a	-20.99	n.a	n.a
10	-16.27	-27.26	-28.18	2547	1695	n.a	-19.52	n.a	n.a

June 2007

Tour-1 day sampling

Depth (m)	Water temp. (°C)	pH	Alk. (meq*l^{-1})	[POC] (mg*l^{-1})	[DIC] (mg*l^{-1})	[DOC] (mg*l^{-1})	δ^{13}C-DIC (‰)	δ^{13}C-DOC (‰)	δ^{13}C-POC (‰)	C/N POM	C/N DOM	pCO_2 alk (µatm)	pCO_2 DIC (µatm)	pCO_2 GC (µatm)	$\delta^{13}CO_2$ aq (‰)
0	7.4	5.93	0.064	0.056	1.67	5.71	-16.82	-27.61	-29.55	11.33	37.51	3964	1409	1893	-19.20
2	7.4	5.96	0.058	0.072	1.66	5.63	-15.87	-27.82	-30.17	10.83	37.12	3352	1485	1744	-18.39
5	7.4	5.92	0.059	0.075	1.71	5.56	-16.16	-27.82	-29.98	11.38	36.41	3738	1735	1824	-18.50
7.5	7.2	5.90	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a

Entrée-5

Depth (m)	Water temp. (°C)	pH	Alk (meq*l^{-1})	[POC] (mg*l^{-1})	[DIC] (mg*l^{-1})	[DOC] (mg*l^{-1})	δ^{13}C-DIC (‰)	δ^{13}C-DOC (‰)	δ^{13}C-POC (‰)	C/N POM	C/N DOM	pCO_2 alk (µatm)	pCO_2 DIC (µatm)	pCO_2 GC (µatm)	$\delta^{13}CO_2$ aq (‰)
0	13.1	6.24	0.034	0.049	1.07	5.49	-14.49	n.a	-30.47	10.54	n.a	1098	704	1141	-18.54
2	13.2	6.26	0.028	0.050	1.25	5.54	-13.68	-27.27	-29.23	10.18	44.67	865	869	1135	-17.85
5	13.2	6.30	0.031	0.050	1.13	5.57	-14.94	-27.41	-28.54	10.45	47.31	873	841	1108	-19.33
10	12.9	6.25	0.029	0.050	1.04	5.60	-14.40	-27.37	-29.39	11.48	47.13	913	968	1118	-18.50
15	12.6	6.23	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
15.5	12.6	6.31	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a